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PLATE I.—The Full Moon, from a Photograph.

ECLECTIC EDUCATIONAL SERIES

ELEMENTS

OF

ASTRONOMY

WRITTEN FOR THE MATHEMATICAL COURSE OF

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BY

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NEW EDITION

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PREFACE.

In this work I have endeavored to describe and explain the Mechanism of the Solar System and of the Stellar Universe. Though written for pupils in the higher grades of public schools, it may be found useful in institutions of still higher rank, and as a foundation for more extended research by the private student.

Although well aware that the rigid principles of mathematics and mechanics form the sole foundation of high astronomical attainment, I have carefully avoided abstruse mathematical demonstrations. Most who study Astronomy desire an accurate knowledge of facts and principles, but need neither for mental culture nor for practical use such a mastery of methods as should fit them to become even amateur astronomers. For such, I have aimed to furnish needed information and instruction. I have assumed that my readers know only the simplest principles of geometry and algebra, and the plainest facts of mechanics and physics. The rest I have endeavored to supply as needed.

The liberality of Publishers has enabled me to insert an unusual number of illustrations. Of the telescopic views, selected from the best authorities, some have lately found their way into American text-books; others appear now for

the first time. The beautiful experiments of Foucault on the Rotation of the Earth, of Fizeau on Light, and of Plateau on Rotation, have not been described hitherto in works of this grade. The same is true of the elegant apparatus of Bache for measuring base-lines, reference having usually been made to the clumsier machinery of the English or French. Many of the diagrams are new, the fruits of hard work in the class-room.

If the omission of the figures of men, animals, and serpents from the star-maps seems to any a questionable innovation, I have to say that my own experience as a teacher long since convinced me that those monstrosities hinder rather than help; and that my practice is sanctioned by Arago, Herschel, Lockyer, Proctor, Guillemin, and others, foremost astronomical writers of the present day.

The Circumpolar Map is drawn on the equidistant projection, the increase in polar distance being always equal to the increase in circular arc. The Equatorial Maps have for base-lines the meridian and the equinoctial—circles easily found, and always in the same position relative to the observer. The projection is the Polyconic, adopted by the U. S. Coast Survey for terrestrial maps, and now first used, so far as I am informed, for astronomical maps. Each tenth declination-parallel is assumed to be the base of a cone, tangent to the sphere in that circle; the spherical surface between that and the next higher parallel is projected into the conical surface, which is then developed upon a plane. As the maps extend but 30° on either side of the meridian, it is believed that the distortion, caused when a spherical surface is represented on a plane, is reduced to a minimum. The stars have been carefully platted from Proctor's Tables.

I am indebted to the courtesy of the Director of the U. S. Naval Observatory, and to the Assistant in charge of the Coast Survey Office, at Washington, for valuable information; to Prof. Henry Morton, Ph. D., of the Franklin Institute, Philadelphia, through whose unsolicited kindness I am able to present the superior engraving of the moon, reduced from a 24-inch photograph in his possession, taken by Mr. Louis M. Rutherfurd, of New York; and to Mr. H. H. Vail, whose careful scrutiny of the proof-sheets has been invaluable.

S. H. P.

CHICAGO, *June* 15, 1869.

REVISION.

The progress of astronomical science compels a revision of this book. Its scope and methods remain, but care has been taken to include all results of established discoveries, especially as to solar and planetary physics; and as to the dimensions and other data of the solar system, dependent on the latest and most trustworthy determinations of the solar parallax.

This work has been aided by the kind criticisms of many teachers, and by the careful assistance of my esteemed co-laborer, Professor Ira O. Baker, of this University.

S. H. P.

ILLINOIS INDUSTRIAL UNIVERSITY,
June 15, 1884.

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ELEMENTS

OF

ASTRONOMY.

CHAPTER I.

ASTRONOMICAL IDEAS REFERRED TO THE POSITION OF THE OBSERVER.

1. **The Horizon.**—Any person in the open air upon level ground, or on the water, finds himself at the center of a large circle bounded by the sky. The sky seems to be the half of a hollow sphere, or a dome, which rests upon the outer edge of the plane on which he stands. The line at which the earth and sky appear to meet is called the *visible*, or *sensible*, *horizon*. The plane which contains this line is the *plane of the horizon*; any plane which is parallel to the plane of the horizon is a *horizontal plane*.

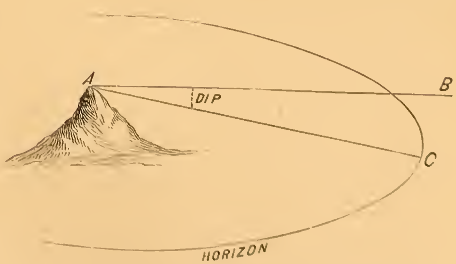

Fig. 1.

2. The horizon is often hidden by houses, forests, or hills, while high objects, as masts or sails of ships, towers, or mountain-tops, sometimes appear beyond. If the

observer ascends some high place, as a spire or hill, the horizon seems to remove as he goes up, and is lower than himself. The amount of its depression below a horizontal line passing through the observer is the *dip of the horizon.* The angle *BAC*, Fig. 1, measures the dip of the horizon at the top of the hill.

3. **Each Observer has his own Horizon.**—Strictly speaking, the horizon of one person differs from that of any other, and each person's horizon accompanies him as he goes from place to place. Practically, persons in the same vicinity have the same horizon.

4. **The Sky.**—The observer is at the center, not only of the visible part of the earth's surface, but also of the sky which covers it. The sky seems to be a surface at a uniform distance, which is immeasurable, or infinite. On this surface the sun, moon, and stars seem to move.

5. **Astronomy.**—The science which treats of the nature and motions of the heavenly bodies is called *Astronomy*,* *The Law of the Stars.* Because these bodies were supposed to influence the fortunes of men, a pretended science, which assumed to read the stars, and to foretell by them future events, was called *Astrology*,† *The Language of the Stars.*

6. **The real Horizon.**—We shall assume that the earth is a globe, surrounded by the sky. The center of the sky is, therefore, readily understood to be at the center of the earth. If a plane pass through the center of the earth parallel to the plane of the sensible horizon, and be extended every way, the line in which it meets the sky is

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* From *αστηρ*, *aster*, a star; and *νομος*, *nomos*, a law. Aster is allied in derivation to *straw* and *strew;* the stars are strewn over the sky.

† From *αστηρ*, and *λογος*, *logos*, a word.

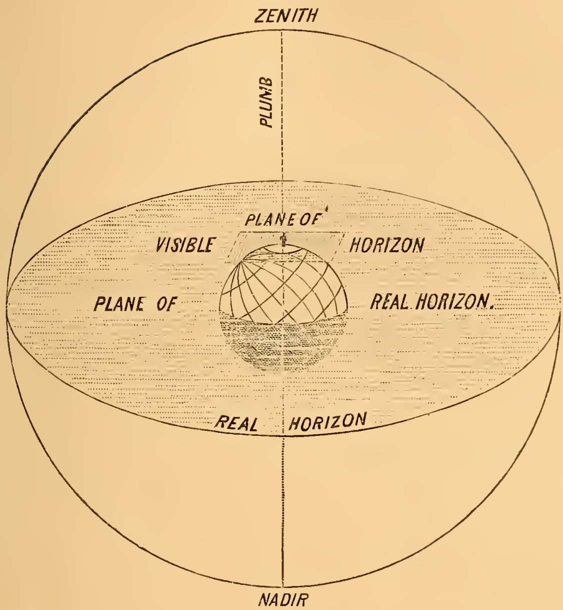

Fig. 2.

called the *real, or astronomical, horizon*. The visible and astronomical horizons seem to meet the sky in the same line, because the distance between them is too small to be perceived on a surface so far away as the apparent surface of the sky.

DEFINITIONS.

7. **A Sphere** is a space bounded by a surface which is at every point equally distant from a point within, called its center.

The line in which a plane cuts the surface of a sphere is the circumference of a circle (Geom. 744).* When the

* The references are to Ray's Geometry.

cutting plane passes through the center of the sphere, the section is a *great circle;* otherwise, it is a *small circle.* In Astronomy, it is convenient to use the word circle to denote what is strictly the circumference of a circle.

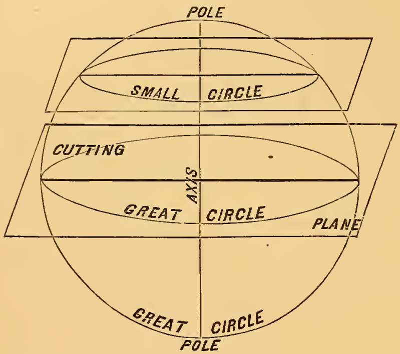

Fig. 3.

The Axis of a circle of a sphere is the diameter of the sphere which is perpendicular to the plane of the circle at its center. The *poles* of the circle are the ends of the axis. The poles of a great circle are equidistant from every point in the circumference of that circle (Geom. 753).

8. Deductions.—The apparent surface of the sky is the surface of a sphere. The real horizon is a great circle, and divides the sky into two hemispheres—one visible, above, the other invisible, below, the horizon.

A plumb-line at the observer is found to be always perpendicular to the plane of the horizon. This vertical line, prolonged each way, is the *axis of the horizon*, and the points where it would pierce the sky are the *poles of the horizon.* That which is above is called the *zenith;* that which is below, the *nadir.*

9. Vertical Circles.—If the observer begin at any point on the horizon, and trace a line on the sky directly upward, it will pass through the zenith, and thence down to the horizon again, to a point opposite to that at which he started. He can readily understand that this line prolonged would pass round under the earth, through the nadir,

back to the starting-point, making a complete circle, half of which would be visible, and half invisible.

This circle is a *vertical circle*, and the plumb, or vertical line, is its diameter.

10. **Definitions.**—A vertical circle is a great circle of the sky, perpendicular to the horizon. The vertical circle which passes through the north and south points of the horizon is the same as the *celestial meridian*, which will be defined hereafter (32). That which passes through the east and west points is called the *prime vertical.*

CO-ORDINATES.

11. **A Point.**—We state the location of a point by giving its direction and distance from some known point or line; or, by giving its distance from two points. Thus a desk in the school-room may be the third in the fifth row; a house is known by its street and number; a town may be ten miles north of Boston, or west of Chicago. In each case, we state *two facts* of direction or distance, which are called *co-ordinates.* So we may locate a star by saying that we saw it at a certain height, and in a certain direction; that is, by giving its *altitude* and *azimuth.*

12. **Azimuth.**—The azimuth of a star is its angular distance from either the north or the south point of the horizon to a vertical circle passing through the star. It may be measured by any instrument for measuring horizontal angles. Direct the sights of a surveyor's compass toward the north, and then turn the instrument until the sights fall on a star; the angle through which they have turned will be the *bearing*, or *azimuth*, of the star.

The record of this angle shows its *origin, amount*, and *direction;* as, N. 20° E., S. 82° 12′ W., etc.

The difference between the azimuth and 90°, or the complement of the azimuth, is called the *amplitude.*

13. Altitude.—The altitude of a star is its angular distance from the horizon, measured on a vertical circle. The *zenith distance* of a star is its distance from the zenith,

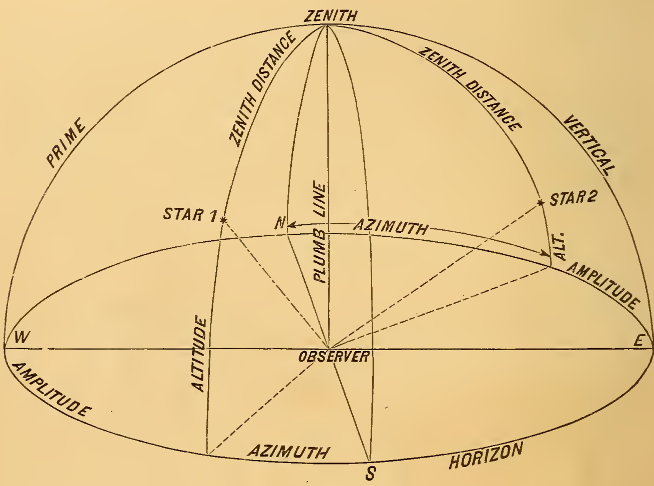

Fig. 4.

measured on a vertical circle. It is the complement of altitude. These angles may be measured by any instrument which moves in a vertical plane, as a theodolite, or railroad transit.

14. ᵀECAPITULATION.

Origin,	The position of the observer.
Primary great circle,	The horizon.
Axis of primary,	The plumb-line.
Poles of primary,	The zenith and nadir.
Secondary great circles,	Vertical circles.
Principal secondaries,	The meridian and prime vertical.
Measured on primary,	Azimuth + Amplitude = 90°.
Measured on secondaries,	Altitude + Zenith distance = 90°.

CHAPTER II.

FORM AND ROTATION OF THE EARTH.

15. The Shape of the Earth. — Several facts prove that the earth is round or spherical.

1. When there is nothing to obstruct or to extend the view, the part of the earth's surface seen from any point is

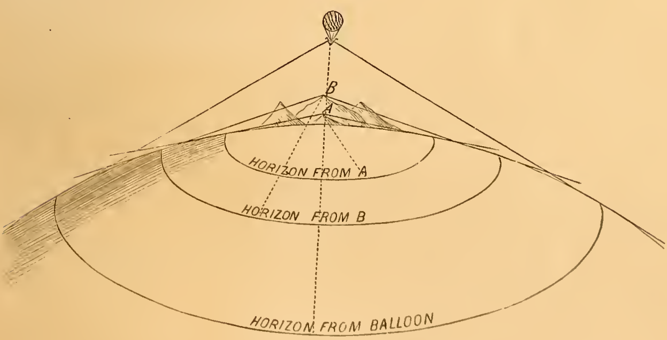

Fig. 5.

a circle. The circle is made larger by raising the observer, as on a spire, on a mountain, or in a balloon. At ordinary heights, a person can see no *farther* on the earth with a telescope than without; he only sees *more distinctly*.

2. The surface of the sea is curved, as is shown by the way in which a ship disappears when it sails from the shore. First the hull goes down behind the horizon, then the sails, finally the mast-heads. If the ship moved on a

flat surface, hull, sails, and masts would all dwindle to a point, and vanish together; they would appear again in a telescope.

A monastery, three stories high, stands on the top of Mt. Toro, in the center of the island of Minorca, in the Mediterranean Sea. As vessels come toward the island in any

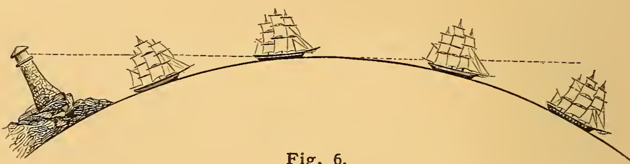

Fig. 6.

direction, the first thing seen by the sailors is the roof of the monastery; then the windows of each story in succession; then the whole building, as if standing on the sea. Presently the mountain appears to rise, and at last the island and its coasts are seen. Similar or opposite facts are observed whenever a vessel leaves or approaches the land.

3. The world has been circumnavigated by many mariners from the days of Magellan until now.

4. The shadow of the earth, as seen in eclipses of the moon, is always round. A sphere is the only solid whose direct shadow is always round.

16. **The size of the earth.**—From the height of a mountain and the distance at which its top is visible at sea, the size of the earth may be computed approximately. Let DBC (Fig. 7) be a great circle of the earth; A, the top of a mountain; B, the farthest point on the circle, from which the mountain may be seen. Then AB is tangent to the circle at B; AD is a secant, and AC its external segment. Therefore, Geom. 333,

$$AC : AB :: AB : AD = \frac{AB^2}{AC} \therefore CD = \frac{AB^2}{AC} - AC.$$

Example.—Suppose the mountain, 2 miles high, is seen at a distance of 126 miles, $CD = 7936$ miles.

17. We do not hesitate to say that an orange is round although its rind is rough, yet its roughness in proportion to its size is much greater than that of the earth's surface where broken by the loftiest mountains. If the highest peaks of the Andes or the Himalayas were accurately represented on an 18-inch globe, they would project from the general surface only about .013 of an inch; the thickness of a sheet of paper, or of a grain of sand.

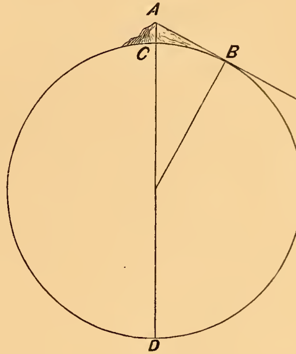

Fig. 7.

18. **The apparent revolution of the sky.**—The most casual observer sees an apparent daily motion of the heavens. The sun rises in the east, passes over through the south, and sets in the west. At night, the stars rise and set in like manner. In the northern sky, the stars seem, to the people in our latitude, to move about a fixed point, which is about half-way between the horizon and the zenith. Patient watching, from hour to hour and from night to night, shows that all the stars, in the south as well as in the north, appear to move about this point, at greater or less distances. The whole circular path of a star is above the horizon, and is visible only when the distance of the star from the fixed point, that is, the radius of the apparent motion, is less than the altitude (13) of the point.

19. **The earth rotates.**—The apparent motion of the heavens from east to west is caused by the actual rotation of the earth from west to east once in twenty-four hours. All the appearances are the reverse of facts. The sun does

not rise, but the horizon sinks below the sun. A star does not come to the meridian, but the meridian sweeps by the star.

20. **The motion of the earth is not felt,** because it is uniform, and we move with it. When gliding in a boat on a smooth stream we often seem to be at rest, while men, trees, and houses pass swiftly by us, yet our reason teaches that we move and that the land is still. Persons who ascend in a balloon see the ground fall quickly from under them, and when they descend the earth seems to rise up to meet them. So, though our senses tell us that the sun and stars rise and set, it is more reasonable that this seeming is caused by the actual rotation of the earth, than that the sky, with all the heavenly bodies, immensely distant from us, moves about the earth in so short a time.

21. **Galileo.**—The doctrine of the rotation of the earth was taught by several ancient philosophers. Copernicus revived it in 1543, and Galileo believed and taught it in the next century. In 1637, at the age of 70, Galileo was forced to read and sign a denial of this belief. It is related that when he rose from his knees after this abjuration, he struck the earth with his foot, and said in an undertone: *E pur si muove*, "and yet it moves," but there is no evidence that he was so imprudent.

DEFINITIONS.

22. **The axis** of the earth is the line about which it rotates. The points where the axis meets the surface are the *north* and *south poles.* The direction in which the earth turns is *east;* that from which it moves is *west.*

If a plane pass through the center of the earth perpendicular to the axis, the line in which it cuts the surface is called the *equator.* The plane of the equator divides the earth into two halves, the *northern* and *southern hemispheres.* *Meridians* are circles on the surface of the earth which pass

through the north and south poles; they are perpendicular to the equator and are great circles.

23. **The longitude** of a place on the earth is the distance of its meridian east or west from an assumed meridian; it is measured in degrees on the equator. English astronomers reckon from the meridian of Greenwich observatory; French, from the observatory at Paris; American, from Washington. The vanity which makes each nation adopt a meridian of its own, only creates confusion. Our globes, maps, and tables usually refer to the meridian of Greenwich, and astronomers are now generally disposed to adopt that meridian as the one from which to reckon longitude.

24. **The latitude** of a place on the earth is its distance north or south from the equator, measured in degrees on a meridian. The latitude of the poles is 90°. *Parallels of latitude* are small circles on the earth's surface, parallel to the equator. Places which have the same distance north or south of the equator are said to be on the same parallel; those which are on the same line from the equator to the poles have the same meridian.

FOUCAULT'S EXPERIMENT.

25. **The rotation of the earth made visible.**—M. Foucault fastened one end of a fine steel wire to the under surface of a high ceiling; to the lower end of the wire he hung a heavy copper ball, carrying below it a steel pointer. This pendulum swung over a place so hollowed out that the pointer would move just over the surface; about the edge of the hollow was laid a ridge of fine sand, which the pointer should pass through at each vibration. That the pendulum might not be moved by any other impulse than the simple attraction of the earth, he drew it aside from its vertical position and tied it by a thread; then when it was perfectly still, the thread was burned off, and the ball began to oscillate.

As the pointer passed through the ridges of sand, it was seen that at each vibration it crossed a little to the right, looking from the center, of the place where it crossed before.

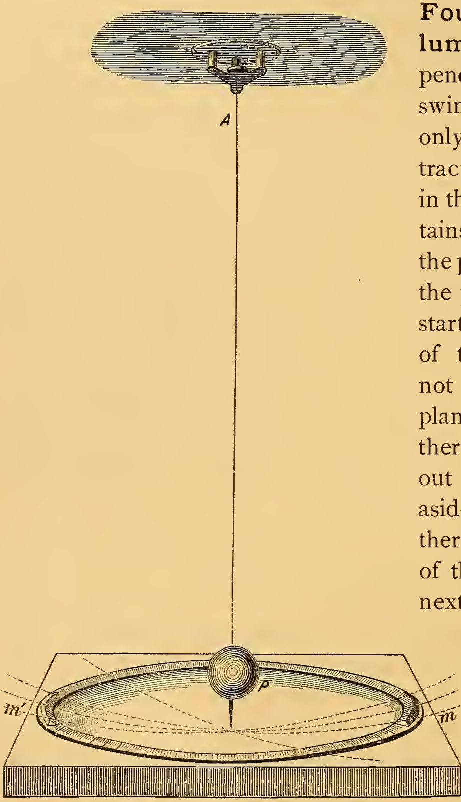

Fig. 8.

26. Theory of Foucault's pendulum. — When the pendulum begins to swing, being drawn only by the earth's attraction, it must move in the plane which contains the three points, the point of suspension, the point from which it started, and the center of the earth. It can not of itself leave this plane of vibration, and there is no force without to cause it to turn aside; it must go on therein to the end of the vibration. The next vibration begins in the same plane, and, therefore, like the first, ends in it, and so each subsequent vibration. That to which the pendulum is suspended has, of course, the motion of the earth at the place where the experiment is performed; but, as the wire is so fastened that no rotary or twisting motion can be communicated to it, the forward motion of

the point of suspension only carries the plane of vibration forward, without twisting it to the right or left.

The ball, then, does not move toward the right; its apparent motion makes visible the actual motion of the earth beneath it, toward the left, that is, toward the east. To view this experiment rightly, the observer should be at the center of the circle; as this is not possible, he should look across the center to the opposite side; then wherever he may stand, the ball will seem to move to the right, while the earth beneath moves toward the left.

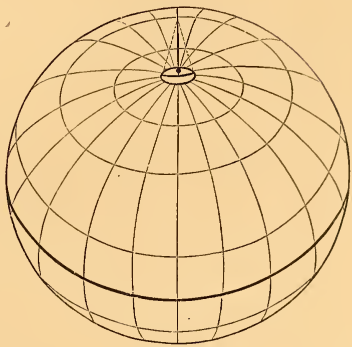

Fig. 9.

27. At the pole (Fig. 9), the point of suspension does not move; the plane of vibration is fixed, and the earth rotates beneath.

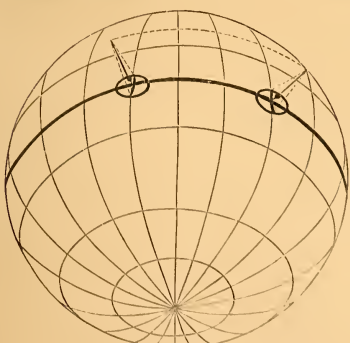

Fig. 10.

At the equator (Fig. 10), the meridians being perpendicular to the equator are parallel to each other, and hence have always the same position relative to the plane of vibration.

Between the equator and the pole (Fig. 11), the meridians converge, or, what amounts to the same, the new positions which each meridian

takes as the earth rotates, make with the old, angles which constantly increase. Hence, as the pendulum maintains its position, although it may have been started in the plane of one of these meridians, an angle is soon formed between them which constantly increases until they again coincide. At the poles, they coincide at the end of 24 hours; between the poles and the equator, the time gradually increases, and at the equator it is infinite.

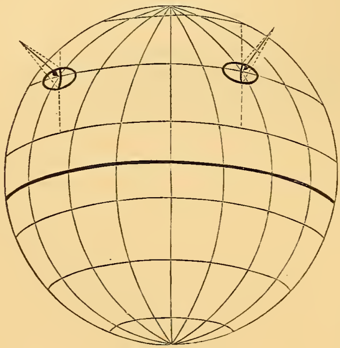

Fig. 11.

28. **The Gyroscope,** when rotating in a vertical plane, remains always in that plane. M. Foucault used this instrument, watching its turning with a telescope, with the same results, explained by the same theory.

29. RECAPITULATION.

Origin,	The rotation of the earth.
Primary great circle,	The equator.
Axis of primary,	The axis of rotation.
Poles of primary,	The north and south poles.
Secondary great circles,	Meridians.
Measured on primary,	Longitude, terrestrial, to 180°.
Measured on secondaries,	Latitude, terrestrial, to 90°.

CHAPTER III.

ASTRONOMICAL IDEAS DERIVED FROM THE MOTION OF THE EARTH.

30. **Axis of the heavens.**—The axis of the earth, extended in each direction until it meets the sky, becomes the *axis of the heavens*, or the line about which the sky seems to revolve. The points where this line meets the sky are the *north and south poles of the heavens.*

31. **Equinoctial.**—If the plane of the equator is extended every way, the line in which it meets the sky is a great circle, called the *celestial equator*, or EQUINOCTIAL. The stars appear to describe circles about the poles of the heavens, parallel to the equinoctial; the circles may be called *circles of daily motion.*

32. **Meridians** are great circles on the sky, perpendicular to the equinoctial, and passing through its poles. Celestial meridians must be imagined on the sky, as terrestrial meridians are imagined on the surface of the earth. As every place on the earth has its own meridian passing through the north and south poles, so each star in the heavens has its meridian passing through the poles of the heavens. When we speak of THE MERIDIAN, as when we say the sun, or a star, comes to, or passes the meridian, we refer to the plane of the terrestrial meridian of the place where the observation is made.

CO-ORDINATES.

33. **Declination.**—The distance of a heavenly body from the equinoctial, measured on a meridian, is called its *declination.* Declination corresponds to terrestrial latitude; it is north or south declination as the object is north or south of the equinoctial. The declination of the poles is 90°.

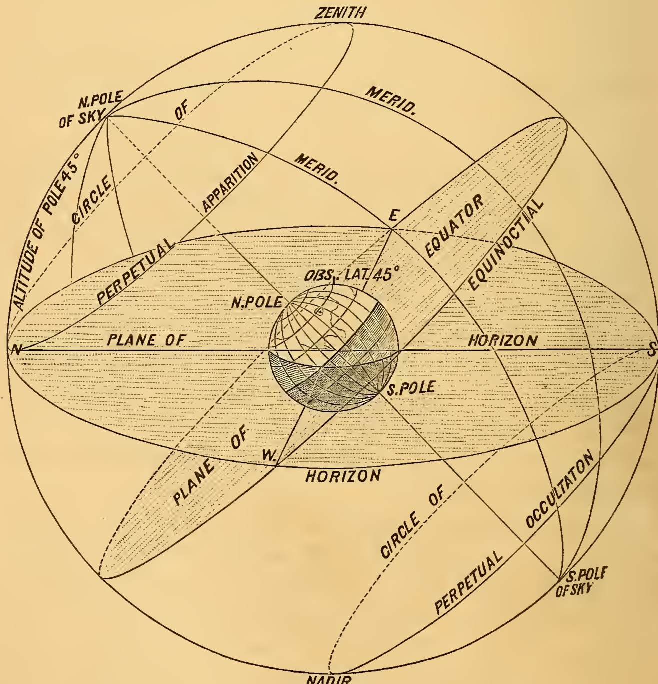

Fig. 12.

34. **Polar distance.**—The *polar distance* of a star is its distance from the nearest pole, measured on a meridian. Declination + polar distance always equal 90°.

35. **Right ascension** corresponds most nearly to terrestrial longitude. It is measured on the equinoctial, eastward from a fixed point, to the meridian of the celestial body. Right ascension is measured from a point called the *vernal equinox*, or first point in Aries, which is indicated by the sign ♈. The meaning of these terms will be explained hereafter. (55.)

36. **The place of a star.**—We locate a place on the earth by giving its latitude and longitude; we locate a star on the sky by giving its declination and right ascension; we tell where it seems to be at any moment when it is above our horizon by giving its altitude and azimuth. We refer

> Latitude and longitude, terrestrial, to the Equator;
> Declination and right ascension to the Equinoctial;
> Altitude and azimuth to the Horizon.

The declination and right ascension of a star are the same for observers at all places on the earth; the altitude and azimuth vary with the position of the observer.

37. **The sky as seen from the pole.**—Let us suppose that a person is at the north pole, and that during the long night there, he sits in the same position for twenty-four hours. The earth rotates, and he turns with it. He is not conscious of motion, and therefore the stars seem to pass before him; they go toward his right hand, pass behind him, and re-appear upon his left. The pole of the heavens is over his head, in the zenith (8). His real horizon (6) coincides with the equinoctial. All heavenly bodies which have north declination, are above the horizon and are visible; all which have south declination are invisible. Celestial meridians coincide with vertical circles (9); the altitude (13) of a star is the same as its declination. The cardinal points can not be distinguished, for north is over his head; south is under his feet; westward is always toward his right hand, and eastward toward his left. Whatever route he takes is toward the south, that is, away from the north pole.

38. **The sky as seen from the equator.**—An observer at the equator will find the poles of the sky in his horizon. The equinoctial will pass through his zenith, and will coincide with the prime vertical (10). The sun and stars near the equinoctial will rise directly in the east; and will set directly in the west; other stars will seem to describe smaller circles whose planes are perpendicular to the horizon, and each star will be visible just twelve hours.

THE LATITUDE OF THE OBSERVER.

39. **The latitude of the observer is equal to the altitude of the pole.**—When the observer is at the equator, his horizon extends to the poles of the sky. If he goes ten degrees north of the equator, his zenith will be ten degrees north of the equinoctial, and his horizon will be removed ten degrees beyond the north pole; the pole will seem to have risen ten degrees above his horizon. At 20° north latitude the altitude of the pole will be 20°. At the pole, latitude 90° (24), the pole of the heavens will be in altitude 90°, or in the zenith (37).

Hence, *the latitude of a place may be found by finding the altitude of the nearest pole.*

40. **The length of a degree of latitude.**—We shall have gone one degree to the north whenever we shall have increased the altitude of the north pole one degree. The length of a degree of latitude differs slightly at different distances from the equator, being shortest near the equator, longest near the pole. The average is about 69¼ miles.

Multiplying the length of a degree by the number of degrees in a circle, we find the circumference of the earth to be 24,930 miles; this gives a diameter of 7936 miles nearly, as found before (16).

41. **The pole star.**—The north pole of the heavens is near a rather bright star, called the North Star, *Polaris*, or

the Pole Star. To the ordinary observer the pole star seems stationary, yet careful observation shows that it has a daily motion about the pole, like other stars in the sky. The sailor on the ocean, the Arab in the desert, the Indian in the forest, each considers this the only motionless star in the heavens, and guides himself by it.

No similar star shows so nearly the place of the south pole of the heavens.

42. **Circle of perpetual apparition.**—The largest circle about the pole, which does not pass below the horizon, is called the *circle of perpetual apparition.* The stars within it do not set, and vanish only because of the superior light of day. A similar circle about the opposite pole, which does not come above the horizon, is the circle of *perpetual occultation.* The stars within this circle never rise. The radii of the circles of perpetual apparition and occultation are equal to each other, to the altitude of the pole, and (39) to the latitude of the place of observation. (See Fig. 12.)

43. To a person south of the equator the circle of perpetual apparition is about the south pole; to one at either pole both circles coincide with the horizon and the equinoctial; to one at the equator, they are nothing.

The heavenly bodies within the circle of perpetual apparition are called *circumpolar* bodies.

44. RECAPITULATION.

Origin,	The apparent daily motion of the sky caused by the actual daily rotation of the earth.
Axis,	The earth's axis prolonged.
Poles of primary,	North and south poles of the sky.
Primary great circle,	The equinoctial.
Secondary great circles,	The celestial meridians.
Measured on primary,	Right ascension, to 360°.
Measured on secondaries,	Declination + Polar Dis. = 90°.

CHAPTER IV.

THE TERRESTRIAL MERIDIAN.

45. **The plane of the meridian.**—A terrestrial meridian has been defined (22) as a circle of the earth which passes through the north and south poles. A line on the floor, a fence, or the foundation of a building, when placed precisely north and south, will mark a meridian line, and the posts of the fence, or the side of the building, if placed truly plumb, will be in the plane of the meridian.

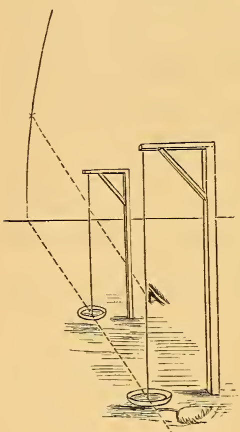

Fig. 13.

46. Hang a plummet by a fine strong line, so that the weight may dip into a vessel of water; this will prevent the line from swinging by the force of the wind. Fix a second line due north of the first, and the two lines will indicate the plane of the meridian quite accurately. While the eye is at one line, any object on the earth or the sky seen to pass the other line may be said to cross the meridian.

As these lines can not be seen in the night, a still simpler way is to fix some stand-point fifty or one hundred feet north or south of a corner of a building, which is usually plumb. A star passes the meridian at the instant when an observer, standing at this point, sees it disappear behind the house.

47. Culminations.—The passage of a star across the meridian is called its *culmination*. As the plane of the meridian extends infinitely in both directions through the axis of the sky, each star passes the meridian twice in traversing its curve of daily motion; once above, and once below the axis. The upper passage is called the *superior*, the lower, the *inferior*, culmination. The inferior culmination is visible when the star is within the circle of perpetual apparition (42).

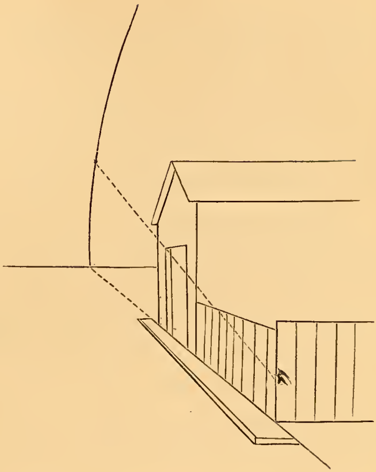

Fig. 14.

THE MEASURE OF A YEAR.

48. The same stars pass the meridian at different hours of different nights.—When the plane of the meridian has been found (46), let us watch the culmination of some star, and let us note the time; suppose it to be eight o'clock in the evening. The culmination of the same star on the next night will occur about four minutes earlier than it did the night before, and so on for the following nights. Patient watching shows that the same star will not come to the meridian again at the same hour until the end of a year.

On any day of the year certain stars will culminate at about midnight; and on every return of that day these stars will again culminate at the same hour. On no other day

of the year will they come to the meridian, except for inferior culmination, at midnight.

49. **The index of a year** is thus found quite nearly. It is the time which passes from the culmination of a certain star at a certain hour, until the next similar culmination of the same star at the same hour.

50. **Observations of the sun at noon.**—When the sun crosses the meridian, we say it is noon. Let us measure the shadow which an upright post casts at noon upon a level surface at its base. From the length of the shadow and the height of the post, we may find by a circular protractor, or by computation, the angle of elevation of the sun, or its altitude (13). The shadow cast by a window-sill upon the floor will answer the same purpose.

51. **From the 20th of March to the 22d of September.**—On the 20th of March we shall find the altitude

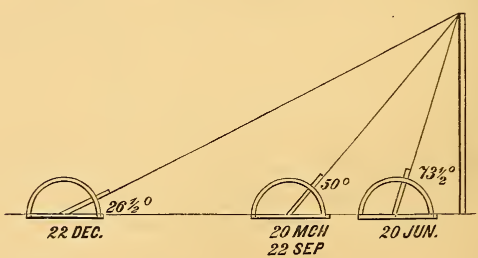

Fig. 15.

of the sun equal to the difference between the latitude of the place and 90°, called the co-latitude of the place; but as the meridian altitude of the equinoctial is equal to the same quantity (App. I), we see that the sun must be on the equinoctial; its declination is nothing (33). On the next day the shadow of the post at noon will be shorter. Thus, day by day, the shadow diminishes until the 20th of June; then

the angle is $23\frac{1}{2}°$ more than the co-latitude of the place, and the sun's declination is $23\frac{1}{2}°$ north. After the 20th of June the shadow increases, and the sun approaches the equinoctial, crossing it again on the 22d of September.

52. **From the 22d of September**, the shadow continues to increase, and the angle to diminish, until the 22d of December. Then the altitude of the sun is $23\frac{1}{2}°$ less than the co-latitude of the place, and the declination of the sun is $23\frac{1}{2}°$ south.

53. **Example.**—When the observer is in lat. 40°, the co-latitude of the place is 50°.

By observation we find, on

March 20,	Sun's altitude,		50°; ∴	Sun's declination,		0°.
June 20,	"	"	$73\frac{1}{2}$;	"	"	$23\frac{1}{2}$ N.
Sept. 22,	"	"	50;	"	"	0.
Dec. 22,	"	"	$26\frac{1}{2}$;	"	"	$23\frac{1}{2}$ S.

THE SUN'S PATH.

54. From these observations we learn:

1. That the sun crosses the meridian at different altitudes, varying regularly during the different seasons of the year.

2. That the sun passes the meridian at the same altitudes at regular intervals of a year.

3. That the sun moves alternately $23\frac{1}{2}°$ north, and $23\frac{1}{2}°$ south of the equinoctial, once each year.

55. **Equinoxes.**—As the horizon (8) and the equinoctial (31) are both great circles, they divide each other into two semicircles (Geom. 748). Therefore, when the sun is on the equinoctial, it is as many hours above as below the horizon, and the day is equal to the night. Hence, the points where the sun in his annual motion crosses the

equinoctial are called *equinoxes.** That which the sun passes in March, going from south to north, is the *vernal equinox;* that passed in September, from north to south, is the

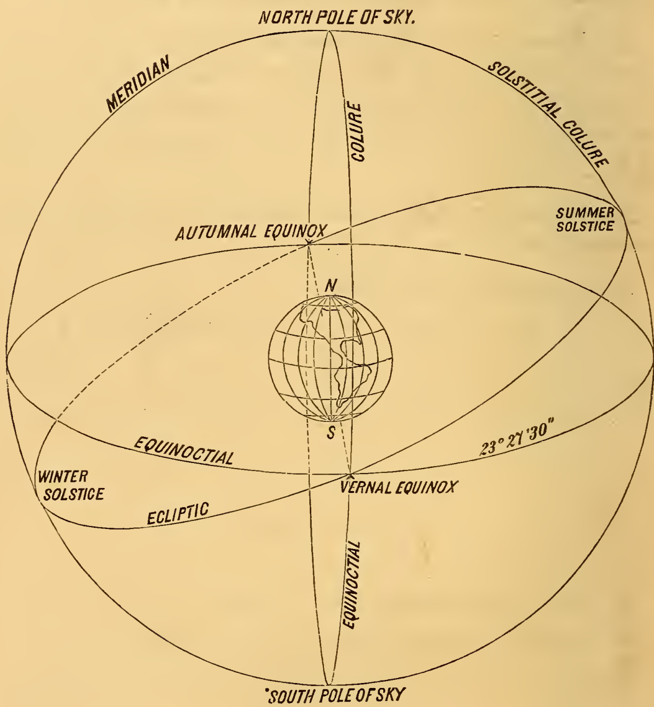

Fig. 16.

autumnal equinox. The vernal equinox is the point from which right ascension is measured (35).

56. **Solstices.**—The sun, having gone farthest from the equinoctial, remains at about the same distance for several days, and then seems to turn and go back again. The

* *Æquus,* equal; *nox,* night.

points where the sun's declination is greatest, are called the *solstices*, or *solstitial points*,* because the sun seems to pause there awhile and then return to the equinoctial. The sun comes to the *summer solstice* on the 20th of June; to the *winter solstice* on the 22d of December. The solstices are 90° from the equinoxes.

57. **Colures.** — The celestial meridian which passes through the equinoxes is called the *equinoctial colure*; that which passes through the solstices is called the *solstitial colure*.

58. **The ecliptic.**—The path which the sun seems to follow in the sky is called the *ecliptic*. It is a great circle, and its plane makes an angle with the plane of the equinoctial of about 23½°.

The angle is exactly 23° 27′ 13″.51 (Jan. 1, 1884).

59. The measure of a year is determined by the apparent motions of a fixed star (49). With a very slight difference, the same time elapses between two successive passages of the sun over a definite point, as an equinox, or a solstice.

60. RECAPITULATION.

The *plane of the meridian* may be shown practically by plumb-lines, or by the vertical walls of a building.

A star *culminates* when it seems to pass the meridian.

A year elapses between two successive culminations of the same star at the same time of night.

A year elapses between two *similar* culminations of the sun.

Equinoxes. The points where the sun crosses the equinoctial.

Solstices. Points at which the sun is farthest from the equinoctial.

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* *Sol*, the sun; *stare*, to stand.

CHAPTER V.

ASTRONOMICAL INSTRUMENTS.

61. The development of the science of Astronomy has depended largely upon the improvement in astronomical instruments. These are in general,

Telescopes,	to see distant objects.
Graduated circles,	to measure angles.
Accurate clocks,	to measure time.

THE TELESCOPE.

62. **Refraction.**—A ray of light which passes obliquely from one medium into another of different density, as from air to glass, or from water to air, is turned or bent from its course. This bending is called *refraction.* Passing into a *denser* medium, the course of the ray is *more nearly* perpendicular to the surface; into a *rarer* medium, its path is *farther* from the perpendicular. A ray which is perpendicular to the surface of the new medium is not refracted.

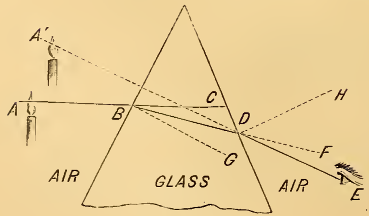

Fig. 17.

The ray AB, which passes into the glass prism, is turned *toward* the perpendicular BG, and goes on to the point D. There it is again refracted, but as it passes into a rarer medium, it is turned *from* the perpendicular, into the line DE. The object A, from which the ray comes, appears to be at A', in the line ED.

63. **A Lens** is a transparent substance, usually glass, whose opposite surfaces are both curved, or one is curved and the other is plane. Sections of different forms are shown in Fig. 18; *a*, plano-convex; *b*, double-convex; *c*, plano-concave; *d*, double-concave; *e*, meniscus.

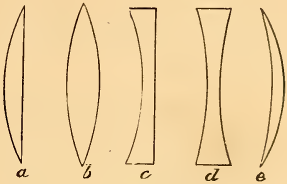

Fig. 18.

The curved surface is usually part of the surface of a sphere. The line which passes through the center of the lens perpendicular to the opposite surfaces is its *axis*.

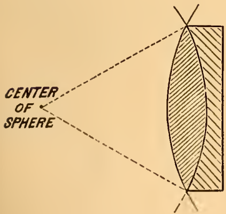

Fig. 19.

The lens may be considered as made of a great number of prisms arranged symmetrically about the axis. Rays which pass through a convex lens are bent toward the axis. Parallel rays are made to meet in the axis at a point called the *focus*. The distance of this point from the center of the lens is the *focal distance*.

THE VISUAL ANGLE.

64. An object which subtends a large angle at the eye is either large or near; one which subtends a small angle is small or distant. The arrows 1 and 4, subtend a large

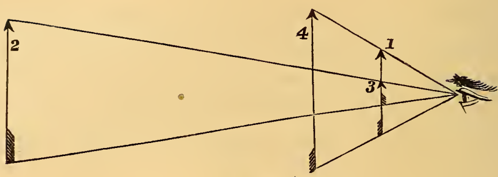

Fig. 20.

angle, while the small arrow 3, and the distant arrow 2, subtend a small angle. The angle at the eye is called the *visual angle.*

65. **Effect of convex lenses.**—A convex lens increases the apparent size of an object seen through it, by increasing its *visual angle.* The arrow 1, seen without a lens appears no larger than the small arrow at 3, included between the lines *a* and *b;* but seen through the lens, the rays *c* and *d* from the ends of the arrow are so refracted as to enter

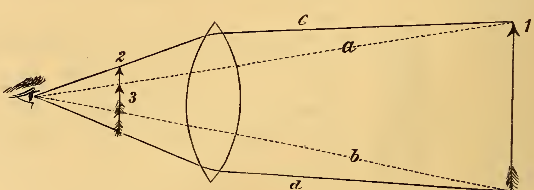

Fig. 21.

the eye, and the object has the apparent size of the larger arrow at 2.

Another lens between the first and the eye refracts these rays again, makes the visual angle still larger, and magnifies the object still more. Several lenses, properly arranged, form the essential part of a *microscope.*

66. **Refracted image.**—All the rays which pass from one point of an object through the lens, are brought together

in a second point at a certain distance, making an image of the first. The same is true of the rays from any other point, and thus every point of the object is represented in an image on the opposite side of the lens. This image may be received on a screen of ground glass, as in a photographer's camera.

67. Illustration.—In the diagram, all the rays which pass through the lens from the point of the arrow are

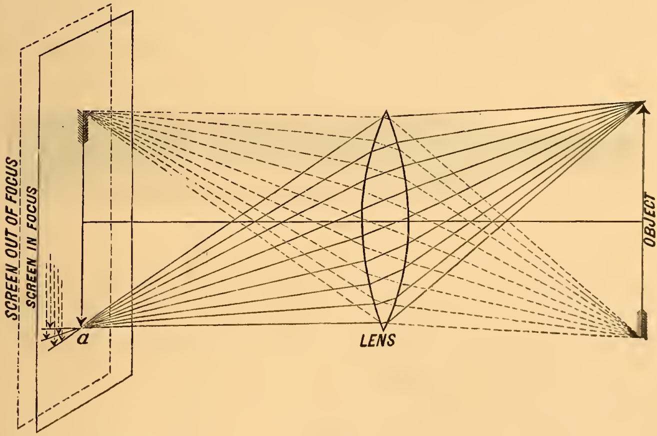

Fig. 22.

united on the screen in the point of the image; all the rays from the tip of the feather are united on the screen in an image of the feather. Were it not for confusion we might draw a series of rays from any other point of the arrow, and find them unite in a point of the image. If the screen is moved a little nearer the lens, or a little farther away, the rays which pass through the lens from the same point of the object, are not gathered into a single point, but are scattered over a small surface, giving a multitude of obscure and interfering images, as at *a*.

REFRACTING TELESCOPES.

68. **A refracting telescope** is a tube containing at one end a large lens, called the *object-glass*, which gathers a great number of rays from the object viewed and condenses them to form an image, and one or more smaller lenses near the other end, which form an *eye-piece*, or microscope, to magnify this image.

69. **A large object-glass** increases the intensity of the light at the image. When a microscope magnifies any number of times, as ten, the light which comes from the

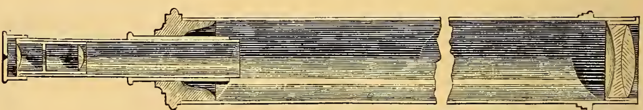

Fig. 23.

object is distributed over ten times the original surface, and the brightness or intensity of the light on any portion is only one tenth as great. Hence we may magnify an object so much, and make its light so feeble, that its form can not be distinctly seen; it fades away as in the twilight. If we would use a higher magnifying power we must find some way to increase the light; in the telescope this is done by enlarging the object-glass.

70. **Example.**—The area of the object-glass of the Chicago refractor, is to that of the Cambridge instrument as 31 is to 25. If the two lenses are precisely equal in other respects, the light will be in the same ratio; if one telescope will admit a magnifying power of 2500, the other can use a magnifying power of 3100.

71. **Power of telescope.**—Different eye-pieces of various powers may be used with the same object-glass, changing for the time the power of the instrument; the limit of power

being fixed by the amount of light furnished by the object-glass. A good lens is highly transparent, of uniform density that it may have uniform refractive power, and quite free from bubbles or scratches. Its size is therefore practically limited by the great difficulty of casting glass in large masses suitable for astronomical purposes.

REFLECTION.

72. A ray of light which meets a plane mirror is turned back, or reflected, and passes away from the reflecting surface, making the angle of reflection equal to the angle of incidence.

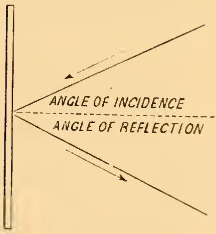

Fig. 24.

73. **A concave mirror** may be considered as composed of a great number of plane mirrors arranged about a hollow spherical surface. The point where parallel rays meet after reflection is called the *focus*.

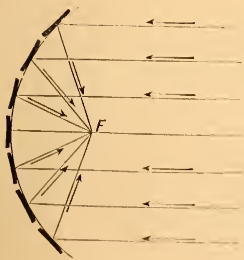

Fig. 25.

74. **Reflected image.** — At a certain distance, all the rays of light which come from one point of the object viewed, to various parts of the mirror, are, by reflection, again brought together, and form the reflected image of the point. In a similar way, an image of the entire object is formed, and may be received on a screen, as in the case of a convex lens (66).

75. **Place of the image.**—The image made by a lens is on the side opposite the object; that made by a mirror is on the same side as the object. We look through the

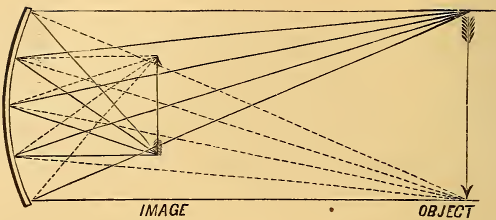

Fig. 26.

lens, toward the object. When using the mirror, we turn away from the object and see an image of it made by the reflecting surface.

REFLECTING TELESCOPES.

76. **A reflecting telescope** is a tube having at one end a concave mirror, called a *speculum*, which gathers the rays of light from the object viewed into an image; the image is magnified by a set of lenses in an eye-piece. The speculum of a reflector evidently serves the same purpose as the object-glass of a refractor; each furnishes a brilliant image for the magnifying power of the eye-piece.

77. Newton placed before the speculum a small plane mirror which reflected the rays a second time and turned them into an eye-piece in the side of the tube (Fig. 27). Gregory used a small concave mirror which returned the rays through a small hole at the center of the speculum (Fig. 28). Herschel, by inclining the speculum slightly, threw the reflected rays directly into the eye-piece fixed obliquely at the mouth of the tube (Fig. 29).

78. The speculum is usually made of some alloy which will take a high polish, and will not tarnish readily.

Silver-on-glass specula have lately been made of good quality and at reduced cost. The concave surface of a block of glass is accurately ground and polished; it is then

coated with a film of silver, chemically deposited, on which an excellent reflecting surface is procured.

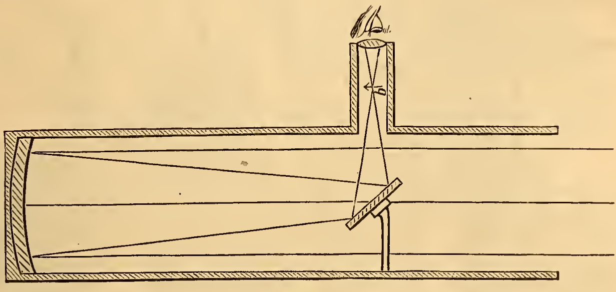

Fig. 27.

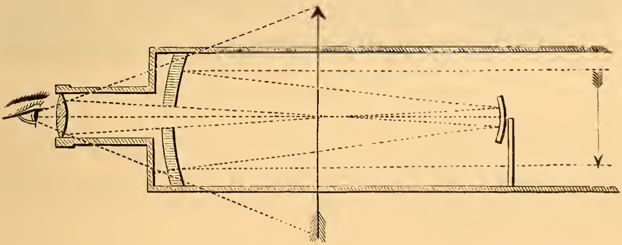

Fig. 28.

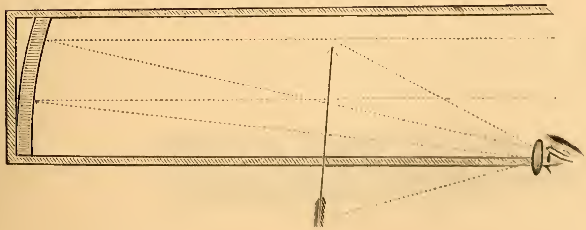

Fig. 29.

The largest refractor yet made is at Pulkova, Russia, 30 inches in aperature.

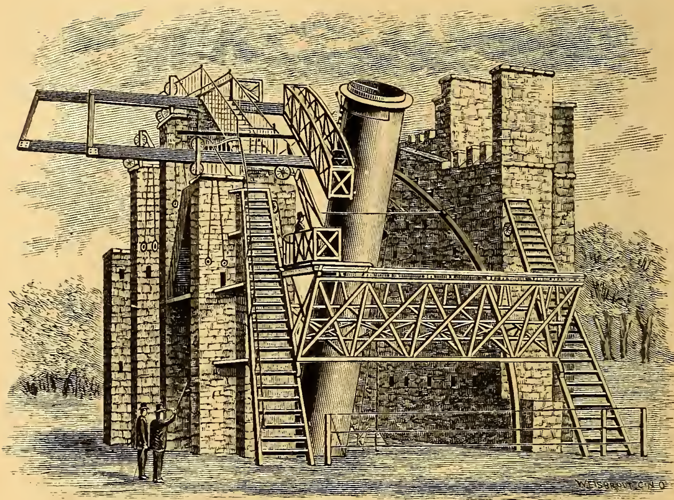

Fig. 30.—Lord Rosse's 6 ft. Reflector.

The largest reflectors are those of Sir William Herschel and of Lord Rosse. The speculum of Lord Rosse's telescope is six feet in diameter.

MEASURING INSTRUMENTS.

79. **The line of collimation.**—If measurement is to be assisted by a telescope, we must know when the instru-

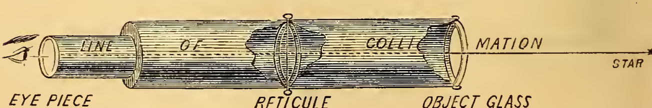

Fig. 31.

ment is pointed precisely at the object whose position is to be found. It is not enough to say that a point is near the

center of the visible field. The line which joins the centers of the object-glass and eye-piece of a telescope is called its *line of collimation*, or its *axis*. The telescope is so placed that one end of this line enters the eye and the other touches the precise point which we observe.

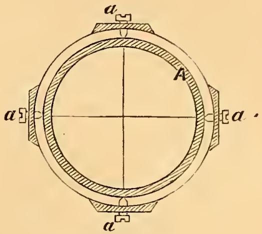

Fig. 32.

80. The reticule.—The axis is marked by two fine wires, one vertical, the other horizontal, which cross in the focus of the object-glass. In some telescopes more wires are used, but in any case the system is called a *reticule*, or net-work. The lines, though called wires, must be the finest possible, and are usually of spider's web. They are fastened to a ring, *A*, which is adjusted in the tube of the telescope by the screws, *a*, *a*. In the day, they are seen as two fine dark lines across the object viewed. In the night, they must be lighted by a lamp placed where its rays may fall on the reticule without coming directly to the eye of the observer. They then appear to be two bright lines against the dark background of the sky.

THE TRANSIT INSTRUMENT.

81. The passage of a star across the meridian has been called its culmination (47); it is also called a *transit*, and a telescope fitted to observe this passage is a *transit instrument*, whose line of collimation must always be in the plane of the meridian, and whose only motion must be on a pivot, at right angles to that plane. The ends of the pivot must rest upon a firm support, usually of solid masonry. The fine lines of the reticule take the place of the corner of the barn, or the plumb-lines of (46), and the observer's sight is assisted by the power of his telescope.

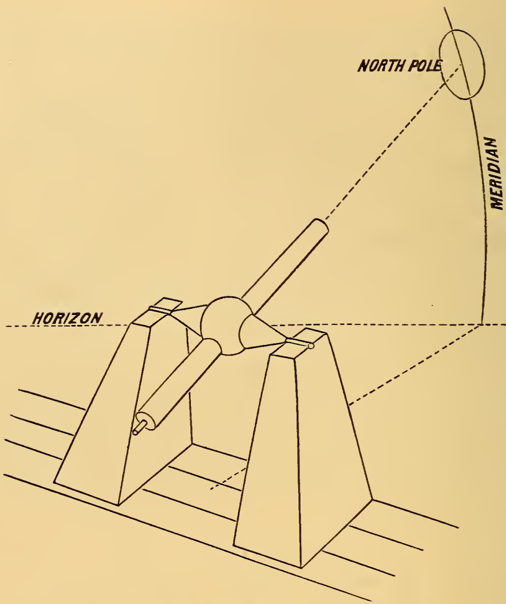

Fig. 33.

The figure must be understood to show only the *essential parts* of the instrument, stripped of all adjuncts or conveniences.

82. The use of the Chronograph in observing a transit.—A sheet of paper is wrapped about a cylinder which is made to revolve at a uniform rate under a pen; the pen draws a continuous line upon the paper. It is held near an electro-magnet, and when the magnet acts the pen is moved slightly aside for an instant, causing a notch in the line. The pendulum of an astronomical clock is so connected with the magnet that a notch is made at each second's beat. The whole apparatus is called a chronograph.*

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* Κρονος, chronos, time; γραφειν, graphein, to write or mark; chronograph, a time marker.

The observer at the telescope has at his hand a key, and when he presses it the pen of the chronograph will make a notch in the line. While he watches a star the clock pendulum is noting seconds. When the star is seen to approach the vertical line of the telescope the observer taps his key quickly several times; then at the instant when the star seems to be on the wire, another tap causes a notch to be made, and its place in the line between two made by the clock, shows the time of the transit.

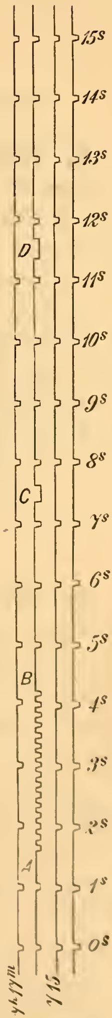


Fig. 34.

This method of observation, invented by Prof. O. M. Mitchel, and known as the American method, is now used in all observatories.

The lines of Fig. 34 are the record of an astronomical clock unwound from a chronograph; the hour and minute being marked at the end of the line, and the seconds by the notches. The notches *AB* show the approach of a star; the transit is marked by the notch *C*. If the space from *C* to 7 is 0.35 of the space 7 to 8, then the record shows that a transit was observed at the first wire at 7 h. 16 m. 7.35 sec.

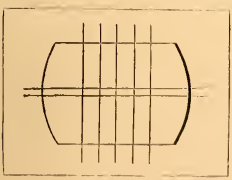


Fig. 35.

83. Additional wires.—To insure still greater accuracy, additional wires are placed on each side of the central wire, and the time is noted as the star passes each in succession. The *average* or *mean* of the observations is taken as the time of the transit, thus:

Transit	over	1st	wire,	11	h.	10	m.	44.25 sec.
"	"	2d	"	"		"		45.10 "
"	"	3d	"	"		"		45.96 "
"	"	4th	"	"		"		46.82 "
"	"	5th	"	"		"		47.66 "
Mean	time	of	transit,	11	h.	10	m.	45.958 sec.

84. **Altitudes.**—By the vertical wire, we may find the instant of the transit of a star; by the horizontal wire, we get its altitude. To measure the altitude, we either fasten a graduated circle to the telescope, and observe what portion of its circumference passes a fixed point as the telescope is moved up or down, or we make the instrument move beside a fixed circle, and so observe the arc passed. The telescope, like that of the transit instrument, must move in the plane of the meridian, upon a pivot which lies due east and west, and rests firmly on solid masonry.

THE MURAL CIRCLE.

85. **The mural circle** is a circle of metal, which, as it turns on its pivot, keeps the telescope attached always in the meridian; the circle is accurately graduated upon its rim. When the telescope is exactly horizontal, a stationary index should point to zero on the circle; as the telescope is moved from that position, a portion of the rim passes by the index, which thus shows the amount of elevation. If the workmanship of the instrument were absolutely perfect, and it could be made so firm as to resist change of form in the slightest degree for any cause, all parts of the rim would indicate the same amount of motion; but since perfection can neither be attained nor kept, several indexes are placed at equal distances about the circle, and the average of their readings is taken. The indexes are microscopes, furnished, like the telescope, with spider-lines (80).

86. The mural circle in the National Observatory at Washington is five feet in diameter; it carries on its edge a band of gold, divided into spaces of 5′ each; it is read

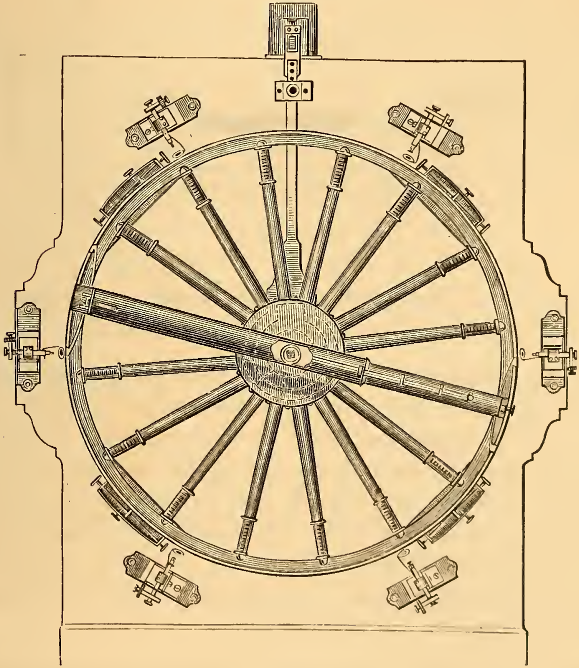


Fig. 36.

by six microscopes, which detect a motion of a single second.

87. A micrometer is a contrivance for measuring very small spaces. Two parallel spider-lines are so arranged in the focus of a microscope that the space between them may be increased or diminished by turning a screw. If the screw has ten threads to the inch, one turn of the screw moves the movable wire one tenth of an inch. Let the head

of the screw be made so large that its rim may contain one hundred easily observed parts, and note how many of these

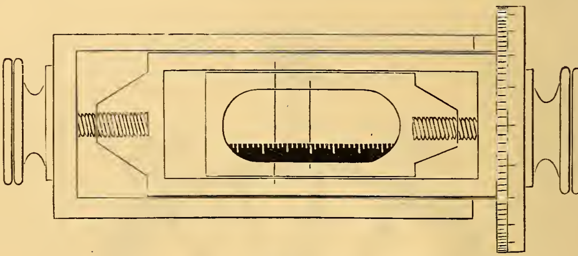


Fig. 37.

divisions pass a fixed index. Each space marks $\frac{1}{100}$ of a turn, or $\frac{1}{1000}$ of an inch, in the motion of the wire.

88. To measure seconds.—In the reading microscopes mentioned before (86), five turns of the screw cover one space on the graduated circle, or five minutes. One turn of the screw gives one minute, and as the head of the screw has sixty divisions, each division indicates one second of arc.

The mural circle may do the work of a transit instrument if furnished with a suitable web of vertical wires.

The transit instrument is sometimes placed in the prime vertical, instead of in the meridian.

89. To find the horizontal position of the telescope.—While readings are made so accurately, it is evidently very important that the starting-point should be as carefully found. The surface of a liquid at rest is horizontal; a trough containing mercury is placed where the telescope of the mural circle may point directly upon its level surface. The telescope is first pointed to a star, and the readings of the circle are noted; then the glass is turned to the image of the same star reflected from the mercury. The lines from the distant star, *SD* and *S′O*, are parallel, and make equal angles with horizontal lines through *D* and *O* (Geom. 138);

the lines $S'O$ and OD make angles of incidence and reflection at O, which are equal (72); the line DO makes angles with the horizontal lines through D and O which are equal (Geom. 125); therefore the image of the star seen in the line DO is seen as far below the horizon as the star itself, on the line DS, appears above. The readings of the circle are again taken, and the true horizontal line of the instrument is midway between the two. A correction is to be made for refraction, which will be explained hereafter (124).

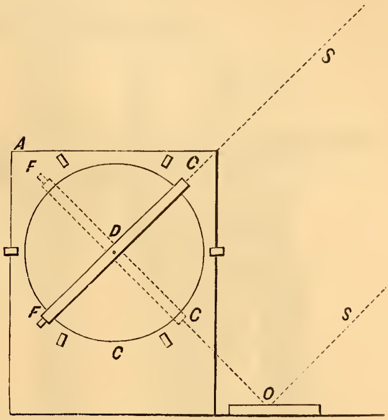


Fig. 38.

90. The meridian circle.—The mural circle has been chosen for explanation because of its simple form. In all modern observatories the mural circle has been displaced by the more complex instrument, called the meridian circle. This is essentially a transit instrument, provided with carefully graduated circles, microscopes for reading, apparatus for inverting, and other conveniences, all of the most accurate workmanship.

In the example presented, we note, first, two substantial iron piers, on which the pivots of the telescope rest. Between the piers the axis carries on either side of the telescope a circle, graduated on its side. There is one microscope for reading the circle on the left, four for that on the right. Each microscope on the right has a micrometer near its outer end for minute reading. The microscopes are carried by the cylinders seen above the piers, and

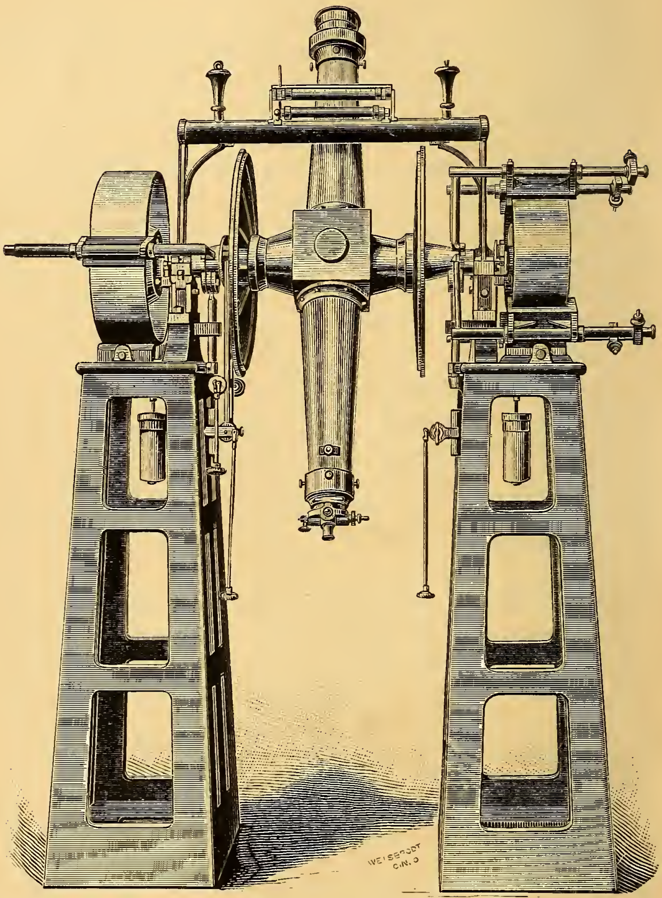


Fig. 39.—Meridian Circle.

may be moved to read different parts of the circles. The bar over the telescope carries the *striding level*. It may be lifted by the handles, reversed to show that the axis is level, or laid aside.

ALTITUDE AND AZIMUTH INSTRUMENT.

91. The mural or meridian circle always points to one vertical circle of the sky; it observes a star only when it

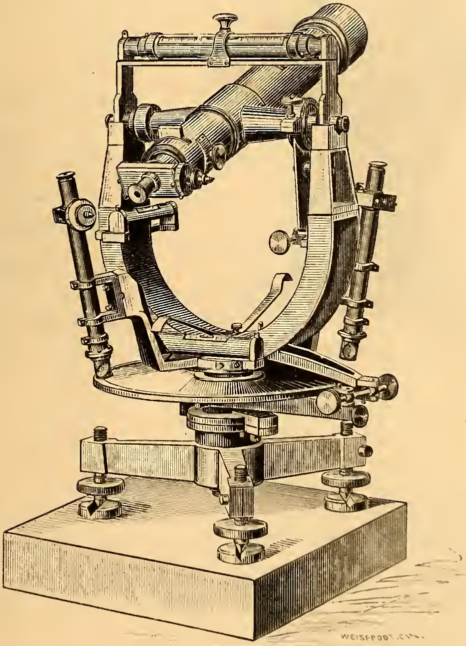


Fig. 40.—A Theodolite.

comes to that vertical. Let us now suppose that the pivot of the telescope is fixed, not upon immovable supports, but to a post which may turn upon its own vertical axis, and let this post stand on a horizontal circle having the same means for careful reading which have been described for circles in a vertical position. The telescope may now be

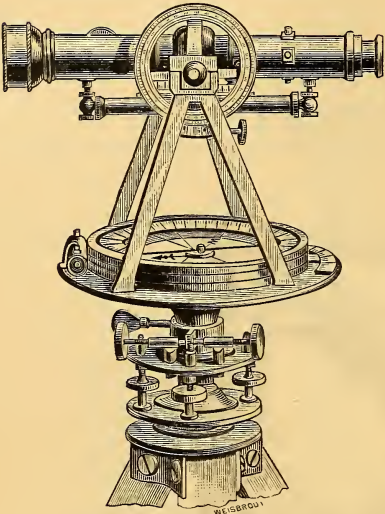


Fig. 41.—Railroad Transit.

turned to any star; the vertical circle of the instrument shows the altitude of the star on a vertical circle of the sky, while the horizontal circle shows the bearing, or azimuth (12).

The common transit of the railroad engineer, when fitted with a vertical circle, is an altitude and azimuth instrument. The vertical circle takes elevations; the horizontal, bearings.

THE EQUATORIAL.

92. **The telescope mounted equatorially.**—When a star has been made to appear in the field of a telescope, it soon passes out of sight, because the earth moves the instrument past the star. If the observer desires a longer view of the object he must follow it with the telescope. His attention is distracted by constant efforts to keep the star in view, and the difficulty increases with the magnifying power of the instrument. It is overcome by a system of machinery for moving the telescope, called an *equatorial mounting.*

The principal pivot is placed parallel to the axis of the sky; it rests on the sloping face of a solid pier, a block of stone, or a heavy frame-work of iron. This pivot is moved by clock-work, and turns the telescope westward as fast as the earth turns eastward, thus counteracting the motion of the

earth. But this would allow the telescope to move only on the great circle of the sky which is at right angles to the axis of the sky—the equinoctial. A second pivot, at right angles to the first, allows the tube to be turned north or south of the equinoctial. The instrument is turned to a star, the secondary pivot is clamped fast, and the machinery turns the first pivot with a motion equal to that of the earth, and in the opposite direction.

Powerful refractors are usually mounted equatorially, since they are used chiefly for studying the physical appearances of the heavenly bodies, and must command the entire sky.

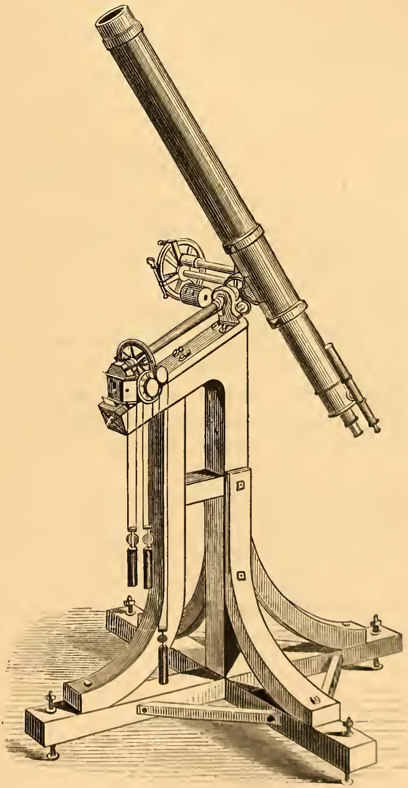


Fig. 42.

93. As mural and meridian circles and transit instruments do not move out of a fixed plane, they require only a narrow opening through which the stars may be seen. Equatorials are usually covered by a large hemispherical or cylindrical dome which has an opening at one side from

the base to the top. The dome rests on rollers, and wheel-work turns it to present the window to any quarter of the heavens.

The instruments described are by no means all that may be found in large and well-appointed observatories. They include, however, the most important, and others differ in detail rather than in principle.

94. RECAPITULATION.

A *telescope* contains a large *lens* or a *mirror*, which furnishes an intensely bright image of a distant object, to be magnified by one or more lenses in the *eye-piece.*

The wires of the *reticule* determine the precise point observed.

For measuring angles, the telescope is attached to a *graduated circle*, either *vertical*, or *horizontal*, or to both.

Observations of *angles* are made more accurate by the *micrometer;* of *time*, by connection with a *chronograph.*

The *transit instrument* observes the *instant* at which an object in the sky passes the meridian.

The *mural circle* gives the *altitude* of such a passage.

The *meridian circle* gives both *time* and *altitude.*

The *altitude and azimuth instrument* gives the place of a star at any time, and in any part of the heavens.

The *equatorial mounting* causes the telescope to follow a star for prolonged observation.

CHAPTER VI.

TIME, LONGITUDE, RIGHT ASCENSION.

95. **Definition.**—Time is a measured portion of duration. It is measured by some kind of uniform motion. The ancients measured time by the flow of water from a vessel called a clepsydra, or of sand from an hour-glass. We measure time by the uniform beats of a pendulum, or vibrations of a balance-wheel, as shown by the movement of hands over the dial-plate of a clock or watch. The standards of measure are found in the real or apparent motions of the heavenly bodies.

96. **Natural units of time.**—Neither of the more obvious events in the sky furnishes an exact standard of time, because the portions of time marked by their recurrence are not of uniform length.

The natural day, whether reckoned from sunrise to sunset or from sunrise to sunrise again, varies in length at different seasons of the year.

The changes of the moon, marking the period we call a month, do not occur at equal intervals, and it is difficult to fix by observation the exact instant of change.

The division of the year into seasons is still more indefinite.

97. **The solar day.**—For purposes of ordinary business, the passage of the sun over the meridian at noon is accepted as marking the middle of the day. The time from one passage of the sun over the meridian until the next, is called

a *solar day*. As these intervals are not of uniform length, their average is a *mean solar day*. A clock which divides a mean solar day into twenty-four equal parts, called hours, is said to keep *mean solar time*.

98. **Mean and apparent noon.**—The instant when the sun crosses the meridian is *apparent noon;* the hour of twelve shown by a clock which keeps mean solar time is *mean noon;* it may be as much as 15 or 16 minutes earlier or later than apparent noon. The reason will be given in the articles on equation of time (233–244).

99. **The civil day** begins at midnight, 12 hours before mean noon, and ends at midnight, 12 hours after mean noon.

100. **The sidereal day.**—The successive transits of any fixed star, as observed by the transit instrument, occur at uniform intervals of 23 h. 56 m. 4.09 sec., mean solar time. This interval is the same at all seasons, and has not varied since astronomical observations began to be made. It furnishes the exact standard of time which we seek, and is called a *sidereal day*, or *star-day*. It is the time occupied in one rotation of the earth.

THE ASTRONOMICAL CLOCK.

101. **The sidereal or astronomical clock** is so regulated as to divide a sidereal day into twenty-four hours. It keeps *sidereal time*, or *star-time*. It is very carefully made, that it may run with the utmost regularity, and it differs from a common clock only in keeping *star-time*, instead of *mean solar time*. With the telegraphic apparatus already described (82), it is of the highest importance in observing transits.

CELESTIAL CO-ORDINATES.

102. **Apparent hourly motion of the stars.**—We have found (19, 20,) that the apparent motion of the stars is

due to the actual rotation of the earth; that, while we speak of a star as coming to the meridian, as it seems to do, in fact the meridian sweeps by the star.

In 24 hours the earth completes one rotation. In that time, any place on the earth—the meridian of the observer—has moved over 360°, passing all the celestial meridians (32) in succession. The meridian, therefore, moves eastward $360° \div 24 = 15°$ in one hour, $15'$ in one minute, $15''$ in one second.

103. Hence, if a star culminates (47) at eight o'clock, and another at 15 m. 45 sec. past 8, the second star is 15 m. 45 sec. of time, or $3° \; 56' \; 15''$ of arc, east of the first.

$$\begin{array}{lllr} 15 \text{ m.} & = 15 \times 15' & = 225' & = 3° \; 45' \\ 45 \text{ sec.} & = 45 \times 15'' & = 625'' & = \underline{\quad 11' \; 15''} \\ & & & 3° \; 56' \; 15'' \end{array}$$

The difference in right ascension (35) of two stars may be found from the difference in the time of their culminations.

104. Conversely, when the difference in right ascension is known, the time of culmination is easily found. If one star culminates at 8 o'clock, when did a star culminate which is $25° \; 16' \; 19''$ west of the first?

$25° \; 16' \; 19'' \div 15$ give 1 h. 41 m. $5\frac{4}{15}$ sec. difference of time.

The star culminated at 8 h. — 1 h. 41 m. $5\frac{4}{15}$ sec. = 6 h. 18 m. $54\frac{11}{15}$ sec.

105. Hour-circles.—The apparent motion of the stars across the meridian marks the flight of time more accurately than the most perfect clock. The arc of the equinoctial included between the meridians of two stars determines the time which must elapse between the transits of those stars. The whole heavens may be conceived to be divided by celestial meridians into spaces 15° wide, and each of these spaces will be traversed by the observer's meridian in one hour. Hence these celestial meridians are called *hour-circles*, and

the angles which they make with each other at the poles are called *hour-angles.*

106. Observations of right ascension.—If we say that a star is 15°, or that it is 1 hour east of another, we evidently state the same fact. To save reduction, therefore, it is customary to state right ascension in time rather than in degrees of arc. But the origin of right ascension is a point on the equinoctial called the vernal equinox (35), hence if the sidereal clock (101) reads 0 h. 0 m. 0 sec. when that point crosses the meridian, we have only to note the reading of the clock at the transit of a star, to obtain its right ascension. The record is made on the chronograph (82) as the star passes the vertical wires of the transit instrument, or of the mural circle.

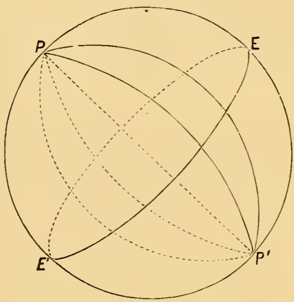


Fig. 43.

107. Observations of declination.—The microscopes of the meridian circle (90) read the altitude of a star at its culmination. The declination of the star is its meridian distance from the equinoctial (33), and is equal to the difference between the altitude of the star and of the equinoctial, each taken on the meridian. If the altitude of the star is the greater quantity, the declination is *north;* if the less, *south.* But the meridian altitude of the equinoctial is equal to the co-latitude of the place of observation (Appendix I); we find, therefore, the declination of a star to be the difference between its meridian altitude and the co-latitude of the observer.

108. The celestial globe.—From the right ascension and declination of a star, its position may be located on a

celestial globe. Having a smooth spherical surface, accurately balanced on an axis, draw a great circle equidistant from the poles, to represent the equinoctial. Take some point on the equinoctial for the vernal equinox, and, beginning at this point, divide the circle into 24 equal parts, or hours; through the points of division and the poles draw the principal meridians or *hour-circles* (105), numbering them at the equinoctial from I to XXIV.

109. **To locate a star.**—Take an arc on the equinoctial, beginning at the vernal equinox, equal to the right ascension, and through the end of this arc draw a meridian; on this meridian, north or south, as the case may be, measure an arc equal to the declination; the point found is the place of the star. A map of a part of the sky is thus made, just as a map of part of the earth's surface is constructed. It will be seen, however, that the map of the sky, on the globe, is the exact *reverse* of that which it represents on the sky. The globe is seen from the outside, while the sky is seen from within, at a point near its center.

A fac-simile of the sky might be made on the inner surface of a large globe, into which the observer might go, but such a contrivance would be neither necessary nor useful, so long as the grand original may be seen nightly over our heads.

TO FIND LONGITUDE.

110. **Terrestrial longitude** may be determined by observations of time. If a star culminates at the meridian of one observer one hour sooner than at the meridian of another, the second observer is 15° west of the first.

The local time is determined for any place by the passage of the sun over the meridian of that place; hence the difference between the local time of two places, shows very nearly the difference between the longitude of those places. If the

time used is sidereal time, the difference in time, reduced to degrees, minutes, and seconds, gives the difference in longitude exactly.

As means of finding longitude is of the highest importance, especially to commerce, great pains has been taken to deter- the longitude of sea-ports, and to find methods for getting longitude at sea. Much of the development of the science of astronomy has grown out of attempts to solve these problems.

111. **Longitude by telegraph.**—As the action of the electric telegraph is almost instantaneous, it furnishes a very exact method of determining longitudes. Connect two observatories, as Cambridge and Chicago; record the transit of a star at Cambridge by the chronograph at each place; when the same star passes the transit wires at Chicago, let the record be again made by each chronograph. The time which elapses between the two observations, when reduced to degrees, gives the difference of longitude of the two places.

112. **Longitude by chronometer.**—A chronometer* is a watch made with special pains to keep time accurately, yet, made and regulated with the utmost care, it rarely runs with absolute precision. The *rate* of a chronometer is the amount which it gains or loses regularly, day by day, or week by week.

The chronometer is first regulated as closely as possible; then its rate is found by comparison with another whose rate is known, or with the movement of the stars; it is then set with the astronomical clock of some observatory. Henceforth, wherever it may be, it shows the time according to the clock of that observatory, correction being made for the rate. Suppose, then, that a sea-captain carries New York time; he observes that, where he is, the sun crosses the

* Χρόνος, *Chronos*, time; μέτρον, *metron*, measure.

meridian at 5 P. M. by his chronometer; he is evidently $5 \times 15° = 75°$ west of the meridian of New York.

Some years since, sixty chronometers were carried several times back and forth between Cambridge, Mass., and Liverpool, England, in order to obtain, by averaging their results, the difference of longitude between the two observatories, and thus to connect the systems of geographical measurement of the two continents.

Mariners usually depend upon chronometers for longitude, and have them rated with great care at every sea-port where time is furnished by astronomical observations. Thus, astronomical science becomes invaluable to the commerce of the world. A ship at the equator will be 15 nautical miles from her supposed place if her chronometer is one minute wrong; at higher latitudes, the error of place will be less, but in either case such an error may cause disaster.

113. Longitude by eclipses of Jupiter's satellites.—The difference of longitude between two places may be found by observing at one place any event in the sky which has been accurately predicted in the time of the other. The planet Jupiter is attended by four moons, which often pass behind the planet or are eclipsed in its shadow; the times of these occultations or eclipses are predicted, and are recorded in a nautical almanac as they will be seen at Greenwich or Washington. The motion of the sea forbids telescopic observations of them on board ship, but on land they are easily seen, and are valuable means of finding longitude.

114. Longitude by lunar observations.—The distance of a given star from the sun or moon, if predicted for a given time and place, may be used as a signal in the sky from which to determine longitude. To use this method, the mariner must have an instrument by which he can measure the angular distance between two heavenly bodies.

115. The Sextant.—The general appearance of the sextant will be learned from the engraving. The index-arm

above the frame moves about a pivot at *I*, where it sustains the *index-mirror;* at the other end, it carries an index over the graduated scale *A*. At *F* is a mirror called the *horizon-glass*, silvered only on its lower half. The observer, holding the instrument by the handle behind the frame, places his eye at the ring *K*, and looks through the open part of the mirror *F* at some object, as a star. He then moves the index along the scale, until the image of another object, as the edge of the moon, reflected from the mirror *I*, appears in the mirror *F* exactly under the star. The angle between the moon and the star is shown by the part of the scale which is traversed by the index (App. II).

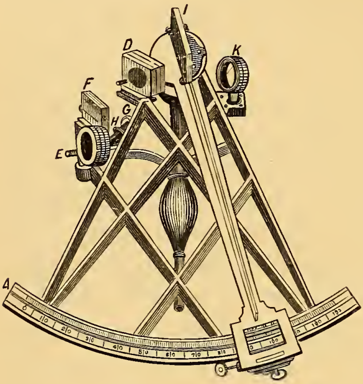


Fig. 44.

At *D* and *E* are several colored glasses, used to protect the eye when the sun is observed; they are turned out of the way at other times.

To find the altitude of a star, we look toward the horizon, bring the image of the star to coincide with it, and read the scale, making correction for the dip of the horizon (2), and for refraction (124).

The sextant is of great value at sea, because its use is not prevented by the motion of the ship.

MOTION IN THE SKY.

116. Motion among the stars.—Every point on the sky passes the meridian at intervals of 23 h. 56 min. 4.09

sec. solar time, or 24 hours star-time (100). If any object, the sun, or a star, does not re-appear at the spider-line of the transit instrument at the interval of a star-day, that object must have moved since its last culmination. To understand which way it has moved, we again call to mind that the earth rotates, not the sky.

THE MERIDIAN, the plane of the terrestrial meridian of the place where WE are observing (32), moves regularly to the eastward as the earth rotates, passing all the celestial meridians in succession, and coming back to its first position in 24 sidereal hours. If, therefore, the star has moved eastward, the meridian does not find it in the old place, but must go on farther to overtake it, and the time between transits will be more than 24 star-hours. If the star has moved westward the meridian will pass it in less than 24 hours. If it has moved directly north or south, the time of transit will not vary, but the mural circle will detect a change of altitude.

117. **Fixed stars** are those which keep their places in the sky. A few stars, observed from night to night, are found to move from place to place, and are called wandering stars, or *planets*.*

THE ECLIPTIC.

118. **The annual motion of the sun.**—The sun passes the meridian at intervals which average 24 h. 3 m. 56.5 sec., star-time. From this it appears that the sun has a regular motion among the stars, eastward; and, by observing the stars which culminate at midnight, that is, just 12 hours after the sun, we find that he makes the entire circuit of the heavens in one year. We have already learned (51–54) that the sun's declination changes from day to day. By noting the sun's position daily on a celestial globe (109),

* Πλανήτης, *Planētes*, a wanderer.

from his declination and right ascension, we trace his apparent annual path among the stars; this we have called the *ecliptic* (58).

In Chapter X, we will inquire if the sun actually moves in this path, or if his motion is only apparent, explained, like his daily rising and setting, by some motion of our own.

119. Distance on the ecliptic, measured eastward from the vernal equinox, is called *celestial longitude.* Distance from the ecliptic, measured on a great circle perpendicular to the ecliptic, is called *celestial latitude.* It should be observed that celestial latitude and longitude do not correspond to terrestrial latitude and longitude. The celestial measurements which are similar to terrestrial latitude and longitude, being referred to the equinoctial, are declination and right ascension (33, 35).

The solstitial colure (57) is perpendicular to the ecliptic. The pole of the ecliptic is on this circle, 23° 27′ 14″ from the pole of the equinoctial.

120. RECAPITULATION.

Time, a portion of duration; measured by *uniform motion.*

Culminations of the *sun* measure *solar* days; of the *stars*, *sidereal* days.

Celestial meridians are *hour-circles;* the angles which they make with each other, *hour-angles.*

Right ascension may be measured in *degrees of arc*, or in *time;* 15 *degrees* are equivalent to *one hour.*

Terrestrial longitude may be determined by
- *The magnetic telegraph.*
- *The chronometer.*
- *Eclipses of Jupiter's satellites.*
- *Lunar observations.*

Any object in the sky which does not return to the meridian in twenty-four hours of sidereal time, has a *real* or *apparent motion.* The *sun* is such a body.

The sun's apparent annual path,	The ecliptic.
Measured on the ecliptic,	Celestial longitude.
Measured from the ecliptic,	Celestial latitude.

CHAPTER VII.

ATMOSPHERIC REFRACTION. DAY AND NIGHT. TWILIGHT.

121. **The latitude of the observer** is equal to the altitude of the nearest pole (39); but, as there is nothing precisely at the celestial pole to mark the point, its altitude can not be directly observed. The stars in the northern sky seem to move about the pole in circles (18), and, if we find the altitude of one of these stars at its superior culmination and again at its inferior culmination, the mean, or the half sum of these altitudes, should be the altitude of the pole.

122. **The apparent daily paths of the stars are not exact circles.**—With the altitude and azimuth instrument (91), we may follow a star from hour to hour, and note its successive positions on a chart. We shall find that its path, although nearly circular, is not exactly so. The horizontal diameter is longer than the vertical, and the lower half of the curve is a little flattened. Hence we suspect that the midway altitude of a circumpolar star is not exactly equal to the altitude of the pole.

123. **The evidence of other stars.**—If we select two stars unequally distant from the pole, the altitude of the pole found by the culminations of the nearer star will be less than that determined by the other. A star 30 or 35 degrees from the pole, observed in latitude 40°, will give a result 12 or 15 minutes greater than that of the pole-star. There must be, therefore, some source of error which causes the stars to

seem higher than they really are, and which produces its greatest effect near the horizon.

ATMOSPHERIC REFRACTION.

124. We have learned that a ray of light which passes from a rarer to a denser medium is bent toward the perpendicular to the surface of the new medium; this bending we

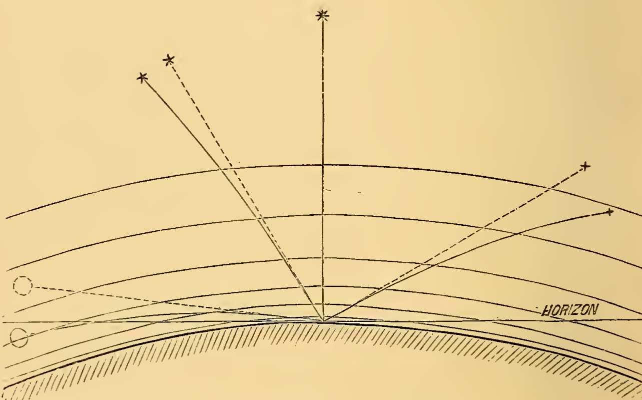


Fig. 45.

have called *refraction* (62). But the air is rarer as the distance from the earth increases. The ray of light which comes into our telescope from a star, has passed through many strata of air, from the rarest, which forms the highest part of the atmosphere, to the denser layer in which the instrument stands. At each increase of density, the ray has been bent downward, and it has come to us, therefore, in a path slightly curved. But the direction which the ray has when it enters the telescope or the eye, fixes the apparent position of the star; *the altitude of the star is therefore increased by atmospheric refraction.*

125. At the zenith, refraction is nothing; near the zenith, it increases slowly; near the horizon, rapidly. It varies also with the density of the air, as shown by the barometer, and its temperature, as shown by the thermometer. At the horizon, it is usually about 36′ 29″; that is, a star which seems to be on the horizon, is really 36′.5 below the horizon, and the ray of light from it, curving round the earth, causes its apparent elevation. The refraction at different altitudes is as follows:*

Altitude.	Refraction.	Altitude.	Refraction.
0°	36′ 29″	10°	5′ 20″
1°	24′ 54″	30°	1′ 41″
2°	18′ 26″	50°	0′ 49″
5°	9′ 52″	90°	0′ 00″

126. Effects of atmospheric refraction.—

1. The sun is visible when it is 36′.5 below the horizon. It, therefore, appears to rise earlier and set later, by the length of time it takes the sun to cross this distance. At the

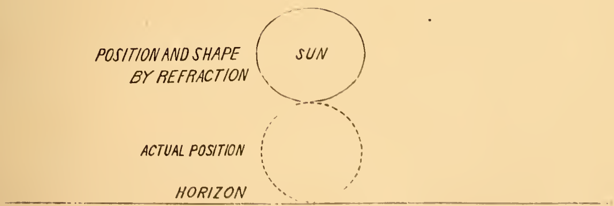


Fig. 46.

equator, the day is longer on this account by about four minutes; at the pole, about four days.

2. The sun is visible on more than half the earth's surface at the same instant. The illuminated half of the world is increased by a belt or zone about 40 miles wide.

* Bessel.

3. The disc of the sun or moon is somewhat distorted when near the horizon. The sun's disc is 32′ broad. When the lower limb is actually in the horizon, refraction raises it to 36′ 30″; at the same time the upper limb, whose real altitude is 32′, is raised by refraction 27′ 30″; it has an apparent altitude of 59′ 30″. The apparent distance between the sun's upper and lower limbs is, therefore, 23′, or 9′ less than the horizontal diameter.

127. The great apparent size of the sun and moon at the horizon, is not caused by refraction. It is an optical illusion, caused partly by an unconscious comparison with

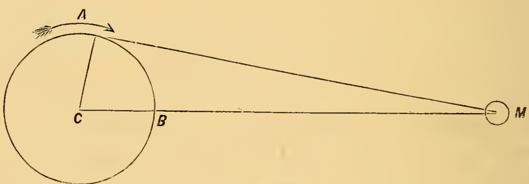


Fig. 47.

intervening objects, and partly by an idea of the great distance of the heavenly body, as compared with the distance of the visual horizon. Experiment shows that the disc of the sun or moon is not broadest when near the horizon.

Roll a sheet of paper into a conical tube so large that while the eye is at the small end the rising moon shall seem just to fill the other; when the moon has risen some distance, the large end of the same tube will appear to be more than filled by the moon's disc. If the moon should pass through the zenith, her diameter there would appear greater by this test than in any other position in the sky.

The moon when in the zenith is actually nearer the observer than when in the horizon by a little less than the radius of the earth. Let an observer be at *A* on the earth; the moon *M* appears in his horizon, at a distance *AM*, the base of the right-angled triangle *ACM*. As the earth turns

on its axis, the observer comes into the position *B*, the moon being in his zenith. The distance to the moon is now *BM*, less than *CM* by the earth's radius *CB*, and less than *AM* by a little less than the earth's radius.

128. Small stars are not visible near the horizon; either the irregular refraction dissipates their light, or the dense vapors near the earth prevent its passage.

129. **True altitude.**—The true altitude of a star is its apparent altitude diminished by the proper correction for refraction (125). All observations for altitude, whether taken with the meridian circle, the altitude and azimuth instrument, or the sextant, require this correction.

TO FIND LATITUDE.

130. **To find latitude by a circumpolar star.**—The latitude is equal to the half sum of the *true altitudes* of any circumpolar star, observed at the place in question. As the circle of daily motion of the pole-star is smallest, that star is best adapted to observations of this kind.

131. **To find latitude by the sun.**—The meridian altitude of the equinoctial equals 90° minus the latitude (51). The declination of the sun is its distance north or south of the equinoctial, measured on the meridian (33). Find the declination of the sun for the day of the year on which the observation is taken (App. III), and take the meridian altitude of the sun with the meridian circle or the sextant (115). If the sun is in north declination, subtract the declination from the altitude; if in south, add the declination to the altitude; the result in each case is the meridian altitude of the equinoctial, which, taken from 90°, gives the latitude of the place. This method is usually adopted at sea.

DAY AND NIGHT.

132. **Relative length of day and night.**—The daily apparent path of the sun in the sky is a circle of daily

motion parallel to the equinoctial (31). That part of the circle which is above the horizon is the *diurnal arc;* that which is below, the *nocturnal arc.* The ratio between them is the ratio between day and night.

133. **At the equator,** where the equinoctial is perpendicular to the horizon (38), the circles of daily motion are equally divided; hence the sun is as long above as below the horizon, during each twenty-four hours of the year, and the day is always equal to the night.

134. **At the pole,** where the equinoctial coincides with the horizon (37), the circles of daily motion are either wholly above, or wholly below, the horizon. When the sun's declination is of the same kind as the pole in question, he is above the horizon; when of the opposite kind, he is below. As the sun has north declination half the year, the day at the north pole lasts six months, and the night six months.

135. **When the sun is at the equinox,** his circle of daily motion is the equinoctial. But the equinoctial and the horizon, being both great circles on the sky (8, 31), divide each other into semicircles (55); hence the day is equal to the night throughout the world, save at the poles; there the sun, being on the horizon, is making the transition between day and night.

136. **In north latitude.**—The diagram shows the position of the circles of daily motion at 40° north latitude. It is evident that of two circles, parallel to the equinoctial, that which is farthest north has the largest proportional part above the horizon. Hence, at this place:

1. The day is longer than the night when the sun's declination is north, and conversely when it is south.
2. The length of the day increases as the sun moves northward until he reaches his greatest northern declination on the 20th of June (51); the days become shorter as the sun moves southward until he reaches his greatest southern declination on the 22d of December (52).

137. Farther north.—As the observer goes north from the equator, the angle between the equinoctial and the horizon becomes less; the circles of daily motion lie more obliquely; those north of the equinoctial show a rapidly

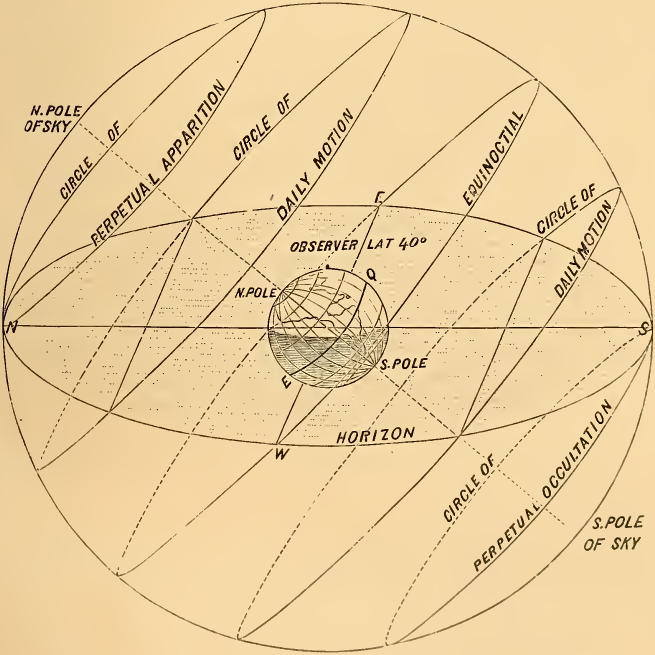


Fig. 48.

increasing diurnal arc; the proportion in those south of the equinoctial decreases as rapidly; long days become longer, and short days shorter. At 66° 32′ north latitude the circle of daily motion on the longest day of the year coincides with the circle of perpetual apparition (42); for, as the declination is 23° 27′, the north polar distance is 66° 32′ (34), which is equal to the latitude. On the 20th of June,

therefore, the sun does not set. Farther north, the sun will not set so long as his declination is more than the distance in degrees and minutes from the place of the observer to the pole, or more than the co-latitude.

138. In the southern hemisphere, all the results described for the northern hemisphere are reversed. The sun passes from east to west through the northern sky; he casts all midday shadows toward the south; the longest days are in December, and the shortest are in June.

139. The amplitude (12) of sunrise and sunset.—The diagram also illustrates the variable position of the sun at sunrise and sunset. When on the equinoctial, the sun rises exactly in the east and sets precisely in the west. As his declination increases northward, the places of both sunrise and sunset move toward the north, and this movement increases with the latitude. At the polar circle, the sun on the longest day merely touches the horizon at the north point, setting and rising again the next instant. On the shortest day, when his declination is south, he appears but for an instant at the south point, rising and setting again immediately.

140. Corrections.—If we seek the exact time or place of sunrise or sunset, corrections must be made:

1. For the effect of atmospheric refraction (129).
2. For the breadth of the sun's disc.

Hitherto reference has always been made to the center of the sun's disc. But sunrise comes at the instant when the first ray crosses the horizon, and sunset is delayed until the last ray vanishes from the upper limb. Hence, as the sun's disc is 32′ broad, sunrise occurs when the sun's center is 16′ below the horizon.

The effect of both these corrections is to lengthen the day, and to shorten the night in all parts of the world.

TWILIGHT.

141. Daylight does not instantly vanish at sunset; it fades away gradually, passing through all the shades of waning light which we call *twilight*. This is caused by the reflection of the light from the upper regions of the air. Let the curve $ACEF$ represent the surface of the atmosphere which surrounds the earth, and suppose the light comes from the sun in the direction indicated. No direct

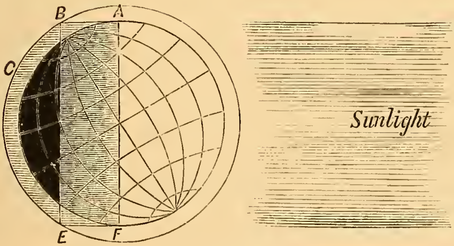


Fig. 49.

rays of sunshine come to the earth beyond the line AF, but some portion of the atmosphere is illuminated as far as the line BE. The observer at A sees the sun in his horizon. The sun has set for the observer at B, but he sees some reflected sunlight from the space between A and B. For the observer at C both direct and reflected light have vanished.

The twilight which precedes sunrise is called the *dawn*.

142. Duration of twilight. — Twilight continues until the sun is 18° below the horizon; some writers say 24°. Its duration must vary somewhat with the condition of the air. The zone which is thus partially lighted is about 1250 miles wide.

The duration varies with the latitude. At the equator, where the daily path of the sun is at right angles to the horizon, the twilight zone is passed in 1 h. 12 m. All travelers in equatorial regions remark the very brief time between sunshine and the darkness of night. As the latitude increases, the sun's path crosses the zone more obliquely, and twilight lasts longer. At lat. 48° 30′, on the night of the Summer Solstice, twilight lasts from sunset to sunrise; at higher latitudes this happens on several nights in succession. At the pole, twilight mitigates the long winter night until the sun has reached a declination 18° on the opposite side of the equinoctial, or for about 75 days.

143. **The crepuscular curve.** — Lacaille claimed to have actually seen, while at sea in the South Atlantic, the shadow of the earth forming a curve on the sky opposite the sun, and following the sun toward the west as the twilight faded. This curve which separates the illuminated portion of the sky from the darker part is called the *crepuscular curve*. If seen at all, it must be under the most favorable circumstances and in the clearest air.

144. **The height of the atmosphere.**—Twilight would last longer if the layer of air about the earth were thicker, or if its upper strata were denser than now. If the crepuscular curve could be clearly seen, the thickness of the atmosphere might be easily computed; on the supposition that twilight lasts until the sun is 18° below the horizon, the height of the atmosphere would be about 40 miles. But the density of the air diminishes with its height above the earth, and in its upper regions it doubtless becomes too rare to reflect much light, if any. Hence, the air may be presumed to extend considerably above that distance.

Without the quality in the air which produces the diffusion or dispersion of light, there could be no twilight; every place not in direct sunshine would be utterly dark, even in the daytime.

145. RECAPITULATION.

The *altitude of the celestial pole* is found from the *culminations of circumpolar stars.*

Correction is required for *atmospheric refraction;* it *increases* the apparent altitude of a celestial object, especially when *near the horizon.*

Terrestrial latitude is found:

1. By *culminations* of *circumpolar stars;*
2. By *meridian altitude* of the *sun* ± *declination.*

Day = night		
At the *equator*, where	the sun's daily path is	*perpendicular* to the horizon.
At the *poles*, where		*parallel* to the horizon.
Elsewhere, when		on the *equinoctial.*
Day > night		
Elsewhere, when		in the *observer's* hemisphere.
Day < night		
Elsewhere, when		in the *opposite* hemisphere.

Twilight is caused by *reflection* of light from upper region of atmosphere; it lasts until the sun is 18° below the horizon.

CHAPTER VIII.

SHAPE OF THE EARTH. GRAVITATION.

146. Public surveys. — The construction of accurate maps is a matter of national importance. When a boundary line between two states or nations is not fixed by some natural landmark, as the channel of a stream, or the crest of a mountain, it is often made at lines of latitude and longitude; these must be determined astronomically. The bounds of many of the states and territories, as well as those between the United States and the British Provinces and Mexico, are fixed at astronomical lines.

Our sea-coast is long and dangerous. The ships which annually enter our harbors, or leave for foreign or domestic ports, bear hundreds of thousands of lives, and about two thousand millions of merchandise. The nation should employ every means, practical or scientific, by which danger may be avoided, and safety insured. To this end, it is necessary to determine the coast-line, and to observe the changes going on there and at the sea-bottom within soundings; to ascertain the laws which govern currents, tides, and winds; to locate light-houses and other signals; and to publish results in reliable maps and charts. For many years our government has conducted such a survey along the seaboard, and has extended it by the great lakes and rivers across the continent.

TRIANGULATION.

147. It is first necessary to determine the latitude and longitude of prominent points along the coast, as hills, spires, and head-lands, and to find the distances between them. A base-line is measured on a piece of level ground, usually

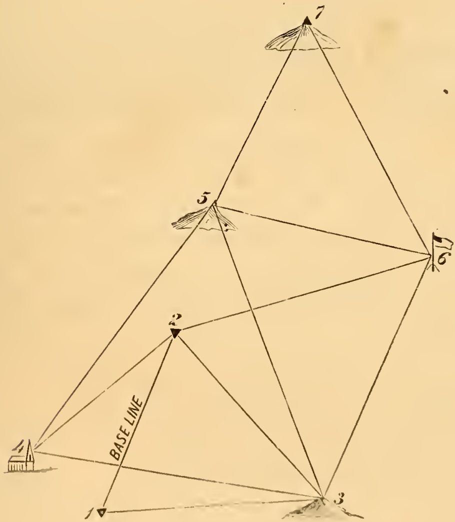


Fig. 50.

from six to ten miles long, and the ends of this line are located astronomically. This line is made the base of a triangle whose vertex is on a distant hill; the angles at the base are observed, and the two opposite sides are found by the methods of trigonometry. These lines are used as bases of other triangles, which are solved in the same way. Thus the triangulation continues until every conspicuous object in the whole country is included in the system.

148. Example.—Suppose that signals have been erected, and a base-line, 12, Fig. 50, has been measured, six miles long. From the stations 1 and 2, the angles 213 and 123 have been observed, and the distances 13 and 23 are computed. 23 is now the base of the triangle 234; 43 is found, which becomes the base of 345, and so on to stations 6 and 7. The line 23 may also be the base of the triangle 236, and thus the station at 6 will be located by two operations which should prove each other.

149. Another proof.—After the work has progressed over a large district, a new base is measured, or the triangles are made to connect with those begun at another line; the agreement of the computed and measured lengths tests the accuracy of the work, including observations, measurements, and computations. A base-line in Massachusetts, on the Boston and Providence Railway, 10.76 miles long, has been connected by triangulation with base-lines at Epping, in Maine, and at Fire Island, south of Long Island. The distance from

Epping Base to Mass. Base is 295 miles		
Mass. Base to Fire Island Base 230 "		
Length of Mass. Base, measured,	56846.09	feet.
" computed from Epping Base,	56846.59	"
" " " Fire Island Base,	56846.32	"
First difference, in 10.76 miles, 6 inches.		
Second " " " 2.8 "		

150. Measuring apparatus.—The base-lines of the U. S. Coast Survey have been measured with the greatest accuracy by an apparatus devised by Prof. A. D. Bache. The rod is a compound bar of iron and brass, so adjusted that the change of length in one part, on account of heat or cold, is exactly counterbalanced by a change of length in the other. The rod is inclosed in a spar-shaped case, painted white to reflect the heat of the sun. Two such

rods are laid in line upon tripods, properly placed, and the contact between the ends is shown by the motion of a very delicate level. Any necessary deviation from a straight or level line is observed and corrected by computation.

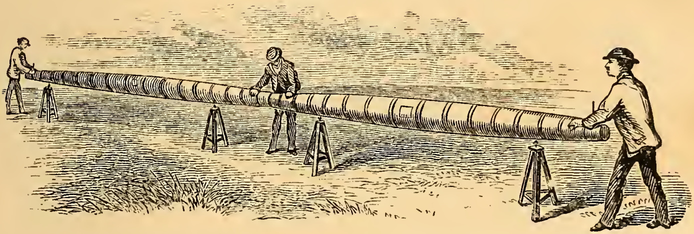
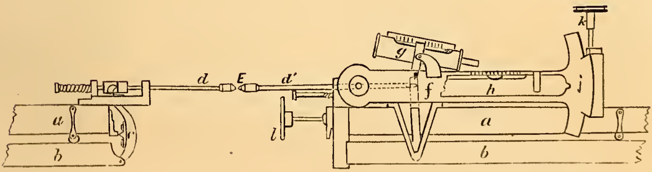


Fig. 51.—Bache's Measuring Apparatus.



Compensation End. **Fig. 52.** Sector End.

a, a, the iron rod; *b, b*, the brass rod; *c*, the lever of compensation, hinged to the brass and resting against the iron; *d, d'*, sliding rods, which meet in agate surfaces at *E*; the rod *d'* pushes at *f* against the lever of contact, which brings the spirit-level *g* into a horizontal position. The slope is shown by the graduated scale *i*, which is moved by the screw *k*, until the spirit-level *h* is horizontal. The screw *l* brings the rods together.

151. Completion of survey.—After the principal triangulation has located the prominent points, minor places are determined in a similar way, and are located on a map. The coast-line is then filled in, soundings are taken off shore, rocks, reefs, and shoals are marked, suitable channels are indicated, and sailing directions added, by which the mariner may steer his craft to a safe anchorage.

Similar surveys have been made in Great Britain and in continental Europe, and have been commenced in India and in South America.

THE SHAPE OF THE EARTH.

152. **The length of a degree of latitude.**—A degree of latitude is such a distance, measured on the meridian, as shall increase the altitude of the pole one degree (40). By the methods described, the length of a degree of latitude has been found in various places, and at various distances from the equator, from Peru, lat. 1° 31′, to Lapland, lat. 66° 20′. Among the results are the following:

Place of measurement.	Lat.			Length of degree in feet.	Measured by.
Peru,	1°	31′	1″	362,790	Bouguer.
India,	16	08	22	363,044	Lambton.
United States,	39	12	00	363,786	Coast Survey.
England,	52	02	20	364,951	Roy; Kater.
Lapland,	66	20	10	365,744	Svanberg.
			69¼ miles =	365,440	

153. **The earth flattened at the poles.** — From the table, it appears that a degree of latitude is shortest near the equator, and becomes longer as we approach the pole. But since near the equator the altitudes of the pole mark degrees by measuring shorter spaces, it is evident that we must be moving on a smaller circle, with a sharper curvature; near the pole the measured degree is longer, the curve must be part of a larger circle, of less rapid curvature. In the diagram, draw *ab*, one third of a quadrant, from the center 1; take a new center, 2, in the line *b* 1 prolonged, and

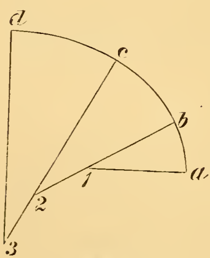


Fig. 53.

draw *bc*, one third of a quadrant; take a new center, 3, in *c* 2 prolonged, and draw *cd*, one third of a quadrant. It is evident that the arc *ab* is less than *bc*, and still less than *cd*, since each is drawn from a nearer center, yet each is opposite an angle of the same amount, as each arc is one third of a quadrant. Hence we see that the curvature of the earth is less at the pole than at the equator; that is, the earth is an *oblate spheroid*.

154. **Dimensions.**—Geodetic surveys in different parts of the earth have been collated, and, as additional material is found, the results vary, as in the following table:

Diameters.	Airy, 1831.	Bessel, 1841.	Clarke, 1880.
Equatorial,	7925.648	7925.604	7926.581
Polar,	7899.170	7899.114	7899.592
Difference,	26.478	26.490	26.989

The center of the earth is 13.5 miles farther from the equator than from the pole. If the earth were represented by a globe one yard in diameter, the polar diameter will be about $\frac{1}{10}$ of an inch too long.

Results lately obtained indicate that the equator is not an exact circle, but that the diameter which passes from longitude 8° 15′ west, to 171° 45′ east of Greenwich, is longer than the diameter at right angles to it by $\frac{3}{5}$ of a mile. The equatorial diameter given above is the mean.

ATTRACTION OF GRAVITATION.

155. Any body, as a stone, unsupported, falls to the earth. But no body has power to move itself; hence the stone comes to the earth because the earth draws it, or because the two mutually draw each other. The mutual attraction of matter at all distances is called the *attraction of gravitation*, or simply *gravity*. The *weight* of a body is the measure of the earth's attraction. A roll of butter weighs a pound if the earth's

attraction for it is the same as for a piece of iron of a certain size which we call a pound.

156. Gravity is in proportion to the mass.—By the *mass* of a body is meant the sum of the particles which compose that body, without reference to its size or *bulk*. If one particle draws with a certain force, two particles will exert twice that force, and a thousand particles, a thousand fold; the attraction of the whole is the sum of the attractions of all its parts. In like manner, its attraction for two particles will be twice that for one, and so on. Hence, at the same distance,

The attraction for one body : the attraction for another : : the mass of the first body : the mass of the second; or

$$G : G' :: M : M'.$$

157. Gravity diminishes in proportion to the square of the distance.—The attraction of a particle goes out from it in every direction: it lies in the center

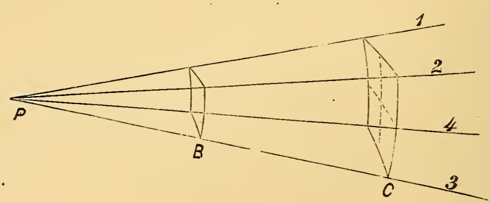


Fig. 54.

of *a sphere of attraction*. A surface at some distance, as at B, receives so much of the attraction from P as is included within the lines 1, 2, 3, and 4; but the surface at C receives the same amount of attraction since it lies within the same lines. If the distance from P to B is 1 unit, and from P to C, 2 units, the surface at C equals four times that at B. Now, if B were removed to C, it would occupy only one fourth the space of C, and would receive from P only one

fourth the attraction received by C, that is, one fourth the attraction which it now receives. At 3 times the distance it would receive $\frac{1}{9}$ the attraction; at 10 times the distance, $\frac{1}{100}$ the attraction, and so on. Hence, for the same mass, gravity is inversely as the square of the distance, or,

$$G : G' :: \frac{1}{D^2} : \frac{1}{D'^2}.$$

158. The general law.—Combining the two preceding results, we have the general law:—The attraction of gravitation is directly as the mass and inversely as the square of the distance.

$$G : G' :: \frac{M}{D^2} : \frac{M'}{D'^2}.$$

Newton proved that the sum of the attractions of the particles which compose the earth may be considered as acting at the center of the earth; as if all the particles with their attractive force were condensed into one at the center. Hence, the distance at which the earth's attraction acts is reckoned from the center, and the weight of a body attracted by the earth will vary inversely in proportion to the square of its distance from the center.

RADIAL AND TANGENTIAL FORCES.

159. Whenever a body, A, moves about a center, C, it obeys two forces, one holding it to C, the other striving to drive it along a tangent toward B. The first may be called a *radial* force; the second, a *tangential* force; they are also called centripetal and centrifugal forces. When a stone tied to a string is whirled about the hand, the impulse given the stone is the tangential force; the strength of the string is the radial force. If the stone is whirled too swiftly, the radial force is too weak to answer its purpose, the string breaks,

and the stone flies off in a tangent from the point where it happens to be at the instant of breaking. Even if the string does not break, it is strained by the whirling stone.

160. Tangential force is produced by the rotation of the earth.—A point on the equator passes through about 25,000 miles in 24 hours; it moves rather more than 1000 miles an hour. A particle at the pole simply turns about in the same time. A particle anywhere in the mass of the earth, either upon or below its surface, moves at a speed which is in proportion to its distance from the axis. But the greater the speed the greater the tangential force, and hence the radial force, which is the weight of the body, is diminished by the tangential force produced by the rotation of the earth.

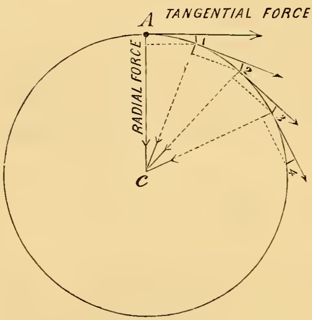


Fig. 55.

161. Illustration.—Let *ABD* represent the earth rotating upon its axis *BD*. Suppose a tube *AC* passing from the surface of the earth at the equator to the center, meets there another tube from the pole, and let the two tubes be filled with water. When the earth is at rest, each particle of water in one tube balances that in the other tube at the same distance from the center, since both are attracted by the same force acting at the same distance. As the earth

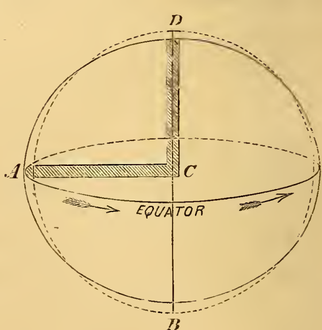


Fig. 56.

rotates, the particles in CD, near the axis, have very little motion, and therefore little tangential force, while those in AC receive more and more tangential force, in proportion to their distance from the center. Hence the weight of the particles in AC is slightly diminished, and therefore a longer column is required to balance the weight of CD, or, as the two communicate, some will pass from CD into AC, until the two again counter-balance. The length of CD is diminished; that of AC is increased. But the same would be true of other tubes similarly placed, or of the entire earth, if it were composed of fluid substance. The fluid near the equator would lose part of its weight in consequence of the rotation and would rise, while the fluid at the poles would sink proportionally.

162. **The interior of the earth is a fluid.** — Whenever a mine or an Artesian well is sunk into the earth, the temperature, commencing about 100 feet below the surface, is found to increase from that point at the rate of one degree of Fahrenheit for every 55 feet in depth. From this, and other reasons, it appears that at the depth of a few miles the heat must be sufficient to melt any known substance. The earth is, then, a mass of melted material, covered with a relatively thin crust of solidified substance. The surface of the crust must conform to the surface of the melted matter beneath, that is, to the shape which a fluid mass of the size of the earth and rotating so rapidly, would assume.

This theory has been disputed, but not controverted.

THE SEA-LEVEL.

163. Were the earth at rest, its particles, being free to arrange themselves in obedience to their mutual attraction, would seek to be equally distant from its center, that is,

they would form an exact sphere. But we have found (152–154) that it is an oblate spheroid, and in its rotation we have found a reason for this shape.

Rotation and gravitation, acting together, give the sea a spheroidal surface called the *sea-level.* To this surface, all geographical measurements of height are referred. One mountain-top may be 13¼ miles farther than another from the center of the earth, yet if both are at the same distance above the sea-level they are said to have the same height.

164. **Weight at the equator and at the poles.**— Any mass weighed at the equator by an accurate spring balance is found to weigh more when carried to high latitudes; its greatest weight would be found at the pole.

The mass is farther from the center of the earth at the equator than at the pole, therefore the earth's attraction for it is less (157). The tangential force produced by rotation counteracts part of the attraction, and also diminishes weight (160).

The mass loses for the first cause about $\frac{1}{590}$; for the second, $\frac{1}{289}$; in all about $\frac{1}{194}$ of its weight; that is, 194 pounds at the equator weighs about 195 pounds if carried to either pole. This accords with experimental evidence. The difference in weight would not be shown by ordinary scales, since the pieces of metal used as weights are affected in the same proportion as the thing weighed.

165. **The pendulum** beats because of the earth's attraction. As the attraction is less at the equator, the pendulum should beat slower there than at the pole, or than at any high latitude. This theoretical inference accords with fact, as shown by experiment in various latitudes.

THE PLUMB-LINE.

166. **The plumb-line** is usually said to point to the center of the earth. It is found to be always exactly

perpendicular to the plane of the horizon; or, to a plane tangent to the surface of the earth at the point of observation. Were the earth a sphere, this perpendicular line would always pass through the center; but because of the actual shape of the earth, it passes through that point only when the plummet hangs at the equator or at the poles; elsewhere, it tends to a point which is away from the center and in the same hemisphere as the place of observation. At *A* and *B* the plumb-line tends toward *C*; at *D* it tends toward a point *F*, in the same hemisphere *ABH*.

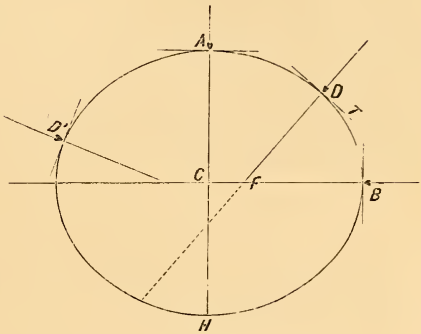


Fig. 57.

167. **The true zenith** is the point in which a line drawn from the center of the earth through the observer, would pierce the sky. The *apparent zenith* is the point where the plumb-line, prolonged, would pierce the sky. At all places, therefore, not on the equator or at the poles, a correction has to be made, varying in different latitudes, whenever the true zenith is to be accurately determined.

168. **Explanation.**—A rigid proof of the cause of the deviation of the plumb-line involves the use of mathematical methods far beyond the scope of this book, but the general statement is as follows: In the figure above, the plummet at *D* hangs perpendicularly to the tangent *DT*, and therefore does not point to *C*, but along the line *DF*. The mass of the earth to the left of *DF*, is evidently larger than the mass to the right, hence (156) its attraction is greater; but the

mass on the left is, as a whole, *farther* from D than the mass to the right, hence (157) its attraction should be less. It is evidently possible that the attraction of the mass to the left is as much less on account of its greater distance, as it is greater by reason of its greater mass, and that the attractions of the two portions, considering both mass and distance, are equal. This is the case, and therefore the plummet takes the direction DF, in equilibrium between the attractions.

THE MASS OF THE EARTH.

The earth's size and shape being determined, the astronomer next seeks to know its *mass* or *quantity of matter.*

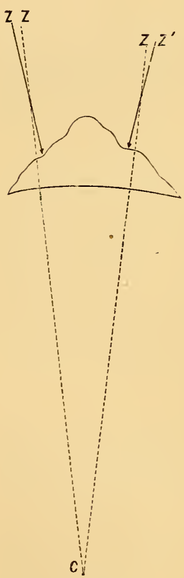


Fig. 58.

169. Maskelyne's experiment.—Maskelyne observed a plumb-line on opposite sides of the mountain Schehallien, in Scotland, noting particularly the place of apparent zenith (167) for each station. From the distance between the two stations, he found that the two plumb-lines should make with each other an angle of 41 seconds, if no mountain were between. But the apparent zeniths of the two places were 53 seconds apart on the sky. Hence it appeared that the attraction of the mountain had drawn the two plummets 12 seconds out of the lines of the earth's attraction, or 6 seconds on each side of the mountain, and from this he found the force of the mountain's attraction as compared with the force of the earth's attraction. From the amount of attraction, the mass was found by the laws of gravitation.

170. Cavendish's experiment.—Cavendish found the mass of the earth thus. He hung a ball of lead, two inches in diameter, at each end of a light wooden beam, suspended by a fine silver wire. He then placed a stout bar of metal, which sustained two balls of lead one foot in diameter, in such a position that the large balls were on opposite sides of the small balls. The whole apparatus was carefully inclosed, to prevent the influence of currents of air, or variation of temperature, and observations were made with

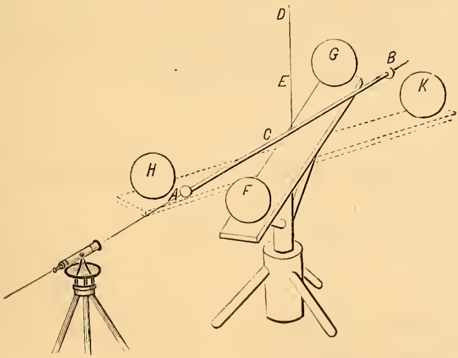


Fig. 59.

AB, the small leaden balls on the rod *C*; *DE*, the suspending wire; *FG*, the large leaden balls in the first position; *HK*, the same in position on the other side of the small balls.

a telescope furnished with spider-lines. When the large balls were placed by the small in one position, the small balls were drawn aside by a certain amount; when the large balls were in the opposite position, the small balls were deflected accordingly. The force which the large balls exerted in twisting the silver wire to draw the small balls out of place, indicated the relation between the mass of the large balls, and the mass of the earth. The experiment has been carefully repeated, both in France and England.

171. **Airy's experiment.**—Airy observed the beating of a pendulum at the top and the bottom of Harton Coal Pit. The pendulum at the bottom of the mine was found to beat *faster* than that at the mouth. If the earth were of uniform density, attraction would decrease as the distance from the center decreases; but the density of the interior may be so great as to *increase* the attraction. (App. IX.) From the results of this experiment, the density of the whole earth was computed.

172. **Results.**—The results of these experiments are not given in weight, but by comparing the weight of the whole earth with its weight if composed of water; that is, by giving the comparative density of the earth.

The density, as found by

Clarke, with plumb-line near mountain,	5.316
Maskelyne, " " " "	4.713
Cavendish, with leaden balls,	5.448
Reich, " " "	5.438
Baily, " " "	5.660
Airy, with pendulum,	6.565
Average result, $5\frac{1}{2}$,	5.523

Baily's result, $5\frac{2}{3}$, is that usually accepted.

The astronomer has now found the units with which he means to measure the universe and weigh the bodies which traverse it. His measuring rod is the radius of the earth; the weight of the earth is his counterpoise.

173. RECAPITULATION.

A degree of latitude is longest near the pole; the earth is *flattened* at the pole,—is an *oblate spheroid.*

The spheroidal shape is caused by *rotation.* Rotation develops tangential force, which diminishes weight. The rapidly rotating

material at the equator is heaped up until its *loss in weight* is balanced by its *increased bulk.*

A body *loses weight* when carried from the center of attraction. If taken from the pole to the equator, it loses weight because both of its rotation and of its greater distance from the center of the earth.

A pendulum beats slowest at the equator for the same reasons.

The *mass*, and thence the *density*, of the earth, have been found:

By Maskelyne, with *a plummet, near a mountain.*

By Cavendish, with *leaden balls.*

By Airy, with the *pendulum.*

CHAPTER IX.

THE DISTANCE OF THE HEAVENLY BODIES.

174. We have already seen (147), that from the length of a base-line and the angles at either end, between the base and lines of sight to a remote point, the position and distances of that point may be determined. By the same method, the distances of the heavenly bodies may be determined.

175. Parallax.—The angle formed at a distant object by lines of sight drawn to two known points is the *parallax*

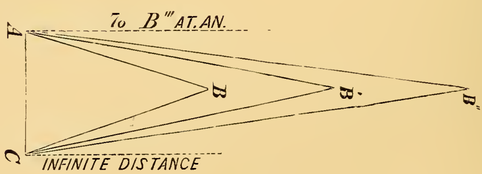


Fig. 60.

of that object. Thus the angle ABC is the parallax of the point B. The angle of parallax increases with the length of the base and diminishes with the distance of the object. The object may be so distant that the parallax is too small to be measured even when the longest base is employed which circumstances will admit. The longest base which the astronomer can find in the earth is its diameter. The

radius of the earth is taken as a convenient unit for expressing large distances.

THE DISTANCE OF THE MOON.

176. The parallax of the moon is found from observations taken at the same time at the ends of the longest practicable base, as the line which joins the observatory at the Cape of Good Hope, with that of Greenwich, or of Berlin. These observatories are favorable for this purpose because they are

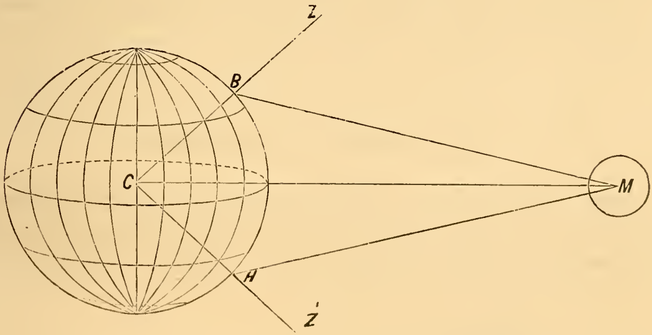


Fig. 61.

nearly on the same meridian, and therefore the moon may be in the field of the meridian circle at each place at nearly the same instant; proper corrections are made for the difference of time, whatever it may be.

Let *B* represent the place of the observer at Berlin; *H*, that of the observer at the Cape of Good Hope; *M*, the moon, and *C*, the center of the earth. The angle at *C* equals the sum of the latitudes of the two places. The angle *CBM* is found by subtracting *MBZ*, the zenith distance of the moon at Berlin, from 180°; the angle *CHM*,

similarly, by taking MHZ' from 180°. But the four angles of a quadrilateral together equal 360° (Geom. 346), hence $360° - (C + B + H) = M$. The four angles of the figure being known, and the sides CB and CH being radii of the earth, the distance CM is easily found by the theorems of trigonometry.

177. Lunar parallax.—The angle at the moon when the base-line is the radius of the earth is the *lunar parallax.* Its value at the mean distance of the moon is found to be $57' \, 3''$; and, the base being a unit, the distance of the moon which gives that parallactic angle is 60; that is, the distance of the moon is sixty times the radius of the earth; in round numbers, $60 \times 4000 = 240{,}000$ miles.

THE DIAMETER OF THE MOON.

178. The angle at M, which has just been called the lunar parallax, is also the angle which the radius of the earth would subtend to an observer at the moon. Hence, if seen at the

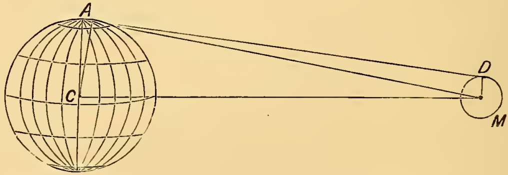


Fig. 62.

moon, the earth would show a disc about 114′ broad. But the moon shows to us a disc about 32′ broad, as measured by our micrometers (89). When two bodies are at the same distance from us, we readily understand that their real diameters are in proportion to their apparent diameters, hence we conclude that:

The apparent diameter of the earth as seen from the moon :
The apparent diameter of the moon as seen from the earth : :
The real diameter of the earth : The real diameter of the moon;

Or, $114' : 31' :: 7912 : 2160 =$ moon's diameter in miles.

Accurate measurements give the diameter 2159.6 miles, or rather more than one fourth the diameter of the earth.

179. The volume of the moon.—The volumes of spheres are to each other as the cubes of their diameters (Geom. 806).

Vol. of E : Vol. of $M :: 7912^3 : 2153^3 :: 1 : \frac{1}{49}+$;
The moon is about $\frac{1}{49}$ as large as the earth.

From the principle that the surfaces of spheres are as the squares of their diameters, we find that the surface of the moon is about $\frac{1}{13}$ that of the earth.

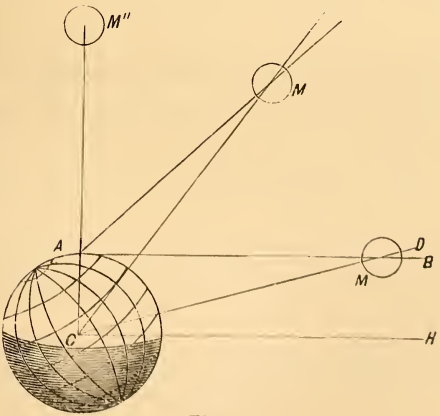


Fig. 63.

180. Horizontal parallax.—When one side of the parallactic angle is in the horizon, the parallax is called *horizontal parallax*. It is also defined as the displacement which a

body in the horizon would have, if seen from the center of the earth rather than from its surface.

181. **Effect of parallax upon altitude.** — When the moon is rising, its center, to an observer at *A* (Fig. 63), is in the line *AB*, while from the center of the earth it would appear in the line *CD*, the angle *AMC* being equal to the lunar parallax 57′. But the angle *AMC* is equal to the angle *MCH* (Geom. 125); therefore, when the moon comes to the apparent horizon, having no apparent altitude, its altitude above the real horizon is 57′. The effect of parallax is to diminish altitude. This effect decreases as the altitude increases, and is nothing when the body observed is in the zenith. Parallax causes the moon to rise above the apparent horizon later, and to set earlier, than the time of passing the real horizon; the effect is opposite to that of refraction (126).

ORBIT OF THE MOON.

182. **The distance of the moon variable.**—The disc of the moon has not always the same apparent breadth. As we can not suppose that its actual size varies, we must conclude that when it appears smaller, it is more distant. The breadth of disc varies inversely as the distance; or,

1st disc : 2d disc : : 2d distance : 1st distance.

Computations of parallax (175) also show that the moon's distance is variable.

183. **The moon revolves about the earth.** — By noting the distance from the moon to some near star, we find, even in an hour or two, that she moves toward the east. Early in the month she appears near the sun in the west, soon after sunset. Day by day she moves eastward, until, in about 14 days, she is on the side of the earth opposite the sun; following her still farther, we find her again between

the earth and the sun. Thus we follow her quite around the earth.

184. **A plan of the moon's path may be made.**—Draw a straight line, *AB*, of any convenient length, to represent the distance of the moon on any day, say the first after the new moon. On the next day, find how many degrees the moon has moved eastward among the stars (103), and represent this change of place by the angle *BAC*. From the variation in the breadth of the disc, find the change of distance (182), and measure this distance on *AC*, using the same scale with which we laid off *AB*. The point, *C*, shows the place of the moon for the second day. In the same way find the points, *D*, *E*, *F*, etc., for the entire month; the curve which connects these points is a plan of the moon's path or orbit.

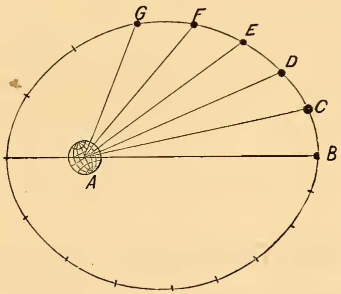


Fig. 64.

THE ELLIPSE.

185. **What is the curve of the moon's path?**—If it is a circle, the earth can not be at the center, for the distances are unequal. The principles of geometry show that this curve is an *ellipse*, and, as we shall have frequent occasion to refer to that figure, we will consider its formation and some of its peculiarities.

186. **To draw an ellipse.**—Set two pins a little distance apart, in a plane surface of board or paper. Tie to each pin one end of a thread which is somewhat longer than the distance between the pins, and placing a pencil against

the thread, draw it about the pins, as shown in Fig. 65. The curve described is an *ellipse*.

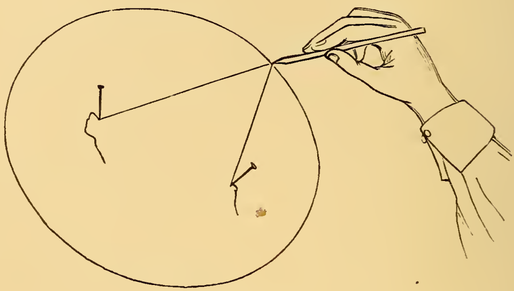


Fig. 65.

187. Definitions.—Observing that the length of the string is constantly the same, we say: An ellipse is a curve such that the sum of the distances from any point of the curve to two fixed points within, is invariable. The space included is called an ellipse as well as the line which includes it.

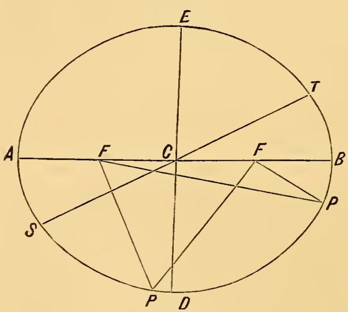


Fig. 66.

Each of the fixed points is a *focus*.

A line drawn through the *foci* and terminated by the curve is the *major axis*.

The middle point of the major axis is the *center* of the ellipse. Any line drawn through the center and terminated by the curve is a *diameter*. The major axis is therefore a diameter.

The *minor axis* is the diameter which is perpendicular to the major axis. Any line drawn from either focus to the curve is a *radius vector*.

The distance from the center to either focus is the *eccentricity** of the ellipse.

188. Deductions.—A little study of the figure shows:

1. That the *radii vectores* vary in length from the shortest, equal to half the major axis *less* the eccentricity, to the longest, equal to half the major axis *plus* the eccentricity.

2. That the sum of the radii vectores which meet at any point of the curve is equal to the major axis.

3. That if the foci are distant from each other, that is, if the eccentricity is great, the ellipse is long and narrow; if the foci are brought near each other, the eccentricity becomes less, and the figure becomes more nearly round; if the foci are brought together, the eccentricity becomes nothing, and the ellipse becomes a circle. Finally, if the foci are placed at the ends of the major axis, the ellipse collapses into a straight line. Hence, an ellipse may have any form between a circle and a straight line.

189. RECAPITULATION.

Parallax is the angle formed by two lines which meet at a distant body, as the moon. From *parallax*, *distance* is found.

The parallax of a body is the angle subtended by the *base* of *parallax* as seen from that body. From *parallax* and *apparent size*, *actual size* is found.

From *apparent size* and *angular motion*, as they vary from time to time, the *path of the moon* is found to be the curve called the *ellipse*.

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* So used in Astronomy. In conic sections, the eccentricity is the ratio between the semi-major axis and the distance above stated.

CHAPTER X.

THE EARTH'S ORBIT.

190. The sun's parallax.—Having found the parallax and distance of the moon, we inquire if the same method will find like quantities for the sun. Trial shows that the solar parallax, whatever it may be, is too small to be obtained reliably by direct observation, as in the former case. But we may obtain by indirect processes what we can not observe directly; to understand these processes, and to be sure of our results, we follow somewhat the outline of discovery. The first point to be settled is the relation of the earth to the sun. Does the sun move about the earth annually, as it seems to do, or does the earth revolve about the sun?

191. The sun vastly larger than the earth.—We have said that the solar parallax can not be directly found, yet for many years our instruments have been so accurate, and our methods so reliable, that we can confidently determine angular quantities of $20''$, $15''$, or considerably less. The parallax must therefore be less than the angle which we can confidently determine; certainly less than $20''$. Supposing it to be $20''$, how large is the sun? The sun's parallax is equal to the *apparent* radius of the earth, *as seen from the sun* (178); the sun's apparent radius, as measured by the micrometer, averages $16' \, 2'' = 962''$. As the real diameters of two objects which are equally distant from an observer, are in proportion to their apparent diameters,

Sun's parallax : App. Rad, of S : : Dia. of E : Dia. of S;

Or, $20'' : 962'' :: 1 : 48$, nearly.

Hence, if the sun's parallax is as small as 20″, the sun's diameter must be 48 times the diameter of the earth. Since volumes are as the cubes of diameters (179), the bulk of the sun is at least 48^3, or 110,592 times the volume of the earth. But our assumed parallax is confessedly too large, hence our computed results fall far short of the truth; we may at least conclude that the sun is vastly larger than the earth.

THE EARTH'S ANNUAL MOTION.

192. The sun's motion may be only apparent.—It may be a result of the real motion of the earth. Let *S* be the sun; *AB*, a path in which the earth moves about

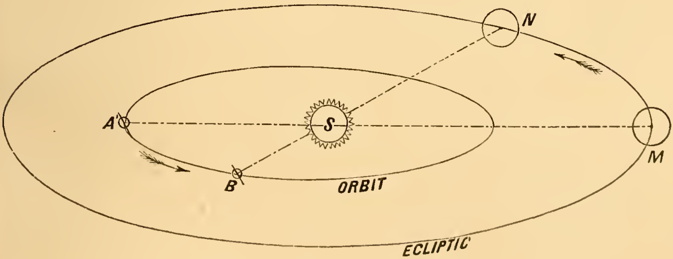

Fig. 67.

the sun. When the earth is at *A*, the sun will be seen against the sky at *M*; as the earth moves to *B*, the sun will seem to move to *N*, and so on to the place of beginning.

193. The sun does not move.—It is more reasonable to believe that a small body moves about one which is vastly larger than itself, than that this large body should move about the smaller one. Since the apparent annual motion of the sun may be produced by the actual revolution of the earth about the sun, we conclude that it is the earth that moves, and that the sun is at rest.

194. **Velocities.**—The *real velocity* of the earth in its path or orbit, is the number of miles which it passes over in a unit of time, as a day, or an hour. This amount we may not know until we find the radius of the orbit, or the distance of the earth from the sun. The *angular velocity* of the earth is the angle formed in a unit of time at the center about which the earth moves. The arc AB represents the earth's real or linear velocity; the angle ASB, its angular velocity, and this angle is measured by the arc MN, which the sun appears to describe in a unit of time.

195. **The angular velocity is not a measure of the linear velocity**, but is greater as the moving body is nearer the center about which it moves. A man walking in a circle around a post at a distance of ten feet, will move through half his orbit, or 180°, by walking about 31 feet; another, 20 feet from the center, would pass through only one fourth of his orbit, or 90°, in walking the same distance. If the two men walk at the same rate, the angular velocity of the man at 10 feet is twice that of the man at 20 feet.

196. **Observations.**—The sun's disc has been measured carefully, day by day, for every day in the year. Whatever the average distance from the earth to the sun may be, we may call it a *unit;* the relative distances for each day are inversely as the breadths of the disc (182).

With the transit-instrument and the astronomical clock, the amount of the sun's apparent motion in right ascension is found for each day (106). From this, the motion in longitude (119) may be determined, either on the celestial globe (108), or by computation. The sun's motion in longitude is the measure of the earth's angular motion. From the two series of observations, a plan of the earth's orbit may be made, as in the case of the moon (184).

197. **Facts observed.**—1. The sun's greatest apparent diameter is measured on the 30th December, and is 32′ 36.4″. The least occurs on the 1st July, and is 31′ 31.8″.

2. The sun's apparent motion in longitude on the 30th December is 61′ 11.1″; on the 1st July, 57′ 13.1″. The earth is nearest the sun, and its angular velocity is greatest, while it is winter in the northern hemisphere.

THE EARTH'S ORBIT ELLIPTICAL.

198. Ancient astronomers knew that the sun's apparent daily motion is not uniform. They accounted for the fact by supposing that the real velocity is uniform, but that it moves in a circular orbit whose center is not at the center of the earth. They supposed that the portion of the sun's path measured off in a day in June seemed smaller than the average, because it was farther away. If their suppositions were correct, the variation in the amount of the sun's daily motion should be in the same proportion as the variation in the breadth of the sun's disc for the same day. That is,

$$32'\ 36.4'' : 31'\ 31.8'' :: 61'\ 11.1'' : 57'\ 13.1''$$

Or, $$1956.4'' : 1891.8'' :: 3671.1'' : 3433.1''$$

But this is not a true proportion, therefore the orbit is not a circle.

199. The ratio of angular motion. — The ratio of greatest and least distances is equal to the ratio of greatest and least discs (182), and is, therefore,

$$\frac{32'\ 36.4''}{31'\ 31.8''} = \frac{19564}{18918} = 1.0341-.$$

The ratio of greatest and least angular motion is

$$\frac{61'\ 11.1''}{57'\ 13.1''} = \frac{36711}{34331} = 1.0693+.$$

Squaring the first ratio, we have 1.06936+, nearly the same as the second ratio; if our divisions are carried to a

greater number of places of decimals, the difference is still less. Hence,

1st ang. vel. : 2d ang. vel. : : 3671.1 : 3433.1
: : 1956.4^2 : 1891.8^2
: : 2d Dis^2 : 1st Dis^2, or

The angular motion af the earth is inversely proportional to the square of the distance from the sun.

But this is a condition which would result from an elliptical orbit, when the *real motion is inversely proportional to the distance.*

200. The ratio of real motion.—Let $ABDE$ be the earth's orbit. Suppose it to be an ellipse (187) with the sun at one of the foci. As the earth moves from A to B, the radius vector SA takes the position SB, and is said to describe the space ASB. The area of this space, considered as a triangle, is the product of $AB \times \frac{1}{2} SC$ (Geom. 386.)

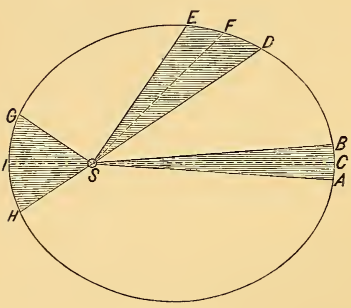

Fig. 68.

Kepler discovered that the areas described by the radius vector in equal times, are equal. That is, if the time in which the earth passes from A to B equals the time in which it passes from D to E, the area ASB equals the area DSE, or,

$$AB \times \tfrac{1}{2}\, SC = DE \times \tfrac{1}{2}\, SF.$$

Multiply the equation by 2, to remove fractions, and change to a proportion;

$$AB : DE :: SF : SC, \text{ or,}$$

The real motion of the earth is inversely proportional to the distance from the sun.

KEPLER'S LAWS.

201. About the year 1601, the German philosopher, Kepler, having adopted the Copernican theory of the solar system, began to study the planetary orbits. He found that they are not circular, as had been supposed. He then invented various hypotheses, and tested each in turn by comparing the position of the planet Mars, as computed by his hypothesis, with its real place as observed. Thus he devised and abandoned *nineteen* before he found one which would answer the test during a planet's entire revolution. The successful hypothesis he announced to the world in his famous laws:

First law. *The path of each planet is an ellipse, having the sun in one focus.*

Second law. *The velocity of each planet is such that its radius vector sweeps over equal spaces in equal times.*

THE LAWS OF FORCE AND MOTION.

202. A body at rest can not put itself in motion: a body in motion can not stop itself, or in any way change either the direction or quantity of its motion. This quality of matter is called *inertia*. *Force* is whatever causes or impedes motion, or changes its direction.

203. Compound motion.—Let a particle of matter, *A* (Fig. 69), be impelled by a force which, in a unit of time, will move it to *B;* at the same instant, let the particle be impelled by a second force, which, in the unit of time, will move it to *C;* in obedience to the two forces, the body will move to *D*, along the diagonal of the parallelogram which has for two of its sides the lines *AB* and *AC*. The line *AD*

is the *resultant* of the two forces. The body will continue to move in the direction of *AD*, and with the velocity of the first unit, until some other force changes the direction or the quantity of its motion.

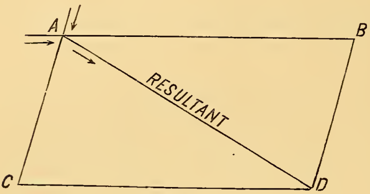

Fig. 69.

204. Curvilinear motion.—How will a body move, if impelled by two forces, one of which acts by a single impulse, the other acting continuously toward the same point? Let a body, *A*, constantly drawn toward a center, *O*, as by the attraction of gravitation, be moved by a single impulse, in the direction *AC*. Let the impulse be sufficient to move the body to *C* in a unit of time, while the radial force alone would move it to *B*. In the first unit of time, the body impelled by the two forces will describe the resultant, *AD*, and will have an impulse which, in the next unit of time, will carry it to *F*, in *AD* prolonged, making *DF* equal to *AD*. But at *D* it again feels the radial force with an amount represented by *DE;* at the end of the second unit of time, it is at *G;* in like manner, it may be traced to *K*, *N*, *R*, etc. But the radial force is said to be continuous, that is, acting at intervals which are infinitely short; hence the lines *AC*, *AB*, and *AD*, etc., while they keep the same ratios to each other, become infinitely small, and the broken line *ADGKN*, etc., becomes a curved line passing through the same points.

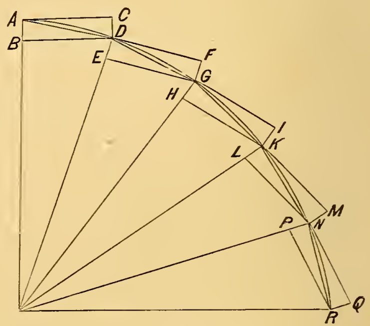

Fig. 70.

Hence a body impelled by two forces, the one acting continuously toward the same point, and the other by a single impulse, describes a regular curve about the given point as a focus. If the curve is such that it returns into itself, it may be shown that it is an ellipse, or a circle, which is one variety of an ellipse (188). In passing along the curve *ADGK*, the rad. vec. *AO describes equal areas in equal times* (App. IV).

205. **Application.**—The laws of curvilinear motion apply to a stone thrown from the hand, to a drop of water spouting from a tube, to a cannon-ball, to the moon revolving about the earth, or to the earth revolving about the sun. In the first cases, the tangential force is the force of projection given to the stone, drop, or cannon-ball; the radial force is the attraction of the earth. In the last cases, the radial force is still attraction of the earth or sun, and the tangential force is the impulse which the moon or the earth possesses as the result of its precedent motion. In any case, the motion continues in an elliptical orbit *forever*, if no other force intervenes to modify or destroy.

206. **Effect of modification of forces.** — The shape of the curve is determined by the relation between the two forces. If the tangential force were weakened, the body would describe a smaller and more flattened ellipse; if that force were quite destroyed, the radial force would at once take the body in a straight line to the attracting body. If the radial force were weakened, the ellipse would be made larger; and if destroyed, the body would obey the tangential force, moving away from the point of tangency in a straight line, which it would continue to follow until it came within the influence of some other modifying force.

207. The present adjustment of the two forces is necessary to retain the earth in its present orbit. It is not true, as many suppose, that the slightest diminution of the projectile force would plunge the earth inward to the sun; it would

merely cause the earth to adopt a new path, which would thenceforth be as stable as the present one, until some new disturbance should again change it. Of course, a constant diminution would produce constant change, which would in the end involve destruction.

208. The eccentricity (187) of the earth's orbit.—Call the mean distance of the sun, 1; the least distance x, and the greatest distance y. Then,

$$x + y = 2.$$

But $\quad x : y :: 1891.8 : 1956.4; \quad$ (194–8)

Whence, $\quad x = 0.9833; \; y = 1.0168.$

The eccentricity of an ellipse is found by subtracting the least from the mean radius. The eccentricity of the earth's orbit is, therefore, $1 - .9833 = .0167$; about .017 of the mean distance.

209. The earth's orbit nearly circular.—If a plan of the earth's orbit were drawn upon a floor, using a mean radius of 10 feet, the eccentricity would be about 2 inches, and the breadth of the ellipse would be about .03 of an inch less than the length. It would require a microscope to distinguish the curve of this ellipse from that of a circle drawn on the same major axis.

210. Perihelion and aphelion.—The *perihelion** is the point in the earth's orbit nearest the sun. A similar point in the moon's orbit is called *perigee*. The point of *aphelion* is that farthest from the sun; the corresponding point in the moon's orbit, farthest from the earth, is called *apogee*. The line which joins the points of perihelion and aphelion, or of perigee and apogee, is the *line of apsides*. It is the only diameter (187) of the orbit which passes through the sun's

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* Περι, *peri*, near; απο, *apo*, away from; ἡλιος, *hēlios*, the sun; γη, *gē*, the earth; αψις, *apsis*, plural apsides, the joining.

center, and therefore the only line passing through the sun which divides the ellipse equally. The earth is at perihelion about January 1; at aphelion, about July 1.

THE CHANGE OF SEASONS.

211. **The center of the heavens.** — Our ideas must expand with our knowledge. At first we found the center of the sky in ourselves (1); then we conceived of it at the center of the earth (6); we must now seek it in that vastly larger body about which the earth revolves, the sun. We must think of the earth as of a body from which we are removed, and in which we have no immediate personal interest; as part of a vast machine, a body making an annual circuit about a remote center, in a nearly circular path, of whose diameter we as yet know only that it is very large. Yet, as compared with even this large diameter, the radius of the sky is infinitely larger. It is so large that, although the earth is moved in six months from one side of its large orbit to the other, the axis of the earth points without variation to the same place on the surface of the sky; and the plane of the equator, when extended outward from any position in the annual path, cuts the sky invariably in the same equinoctial line.

212. Astronomical apparatus and diagrams always fail to represent astronomical proportions. Either the bodies are too small to be seen, or the curves are too large to be put on paper. But they may exhibit the *relations of parts*, and for that purpose Fig. 71 is inserted. The earth is represented as passing round the sun in an elliptical orbit, the sun being in one of the foci (201). The plane of the earth's orbit extended cuts the surface of the sky in a great circle, which is the apparent annual path of the sun, the ecliptic (58). The plane of the earth's equator extended cuts the sky in the equinoctial (31). These two great circles bisect

each other (Geom. 748), and the line common to the planes of both passes through the sun and through the equinoxes (55). From the time of the autumnal equinox, in September,

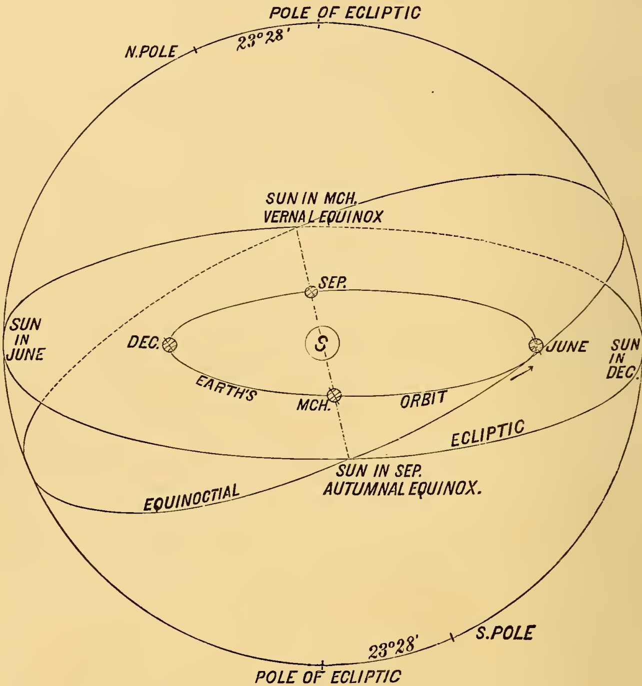

Fig. 71.

to the vernal equinox, in March, the sun appears in the southern sky; during the remainder of the circuit, he appears in the northern sky.

213. The sun longest in the northern sky.—The earth's radius vector is least in December (197). Hence the line which joins the equinoxes divides the orbit into two unequal parts, the less being that traversed in our winter.

But the times are as the areas described by the radius vector (201); hence the earth passes more quickly over the northern or smallest part of its orbit, and the sun seems to pass more quickly over the opposite southern portion of the ecliptic. Although the sun is north of the equinoctial more than half the days of the year, his distance from the earth is more than the average; the aggregate amount of heat received by the northern hemisphere is therefore no greater than that received by the southern.

POSITION OF AXIS.

214. **The change of seasons** can not, therefore, be due to the difference of the earth's distance from the sun at different times of the year. It is caused by the annual revolution of the earth, combined with the position of the earth's axis as related to the plane of its orbit.

215. **If the earth's axis were perpendicular** to the plane of its orbit, there could be no change of seasons. The equinoctial would coincide with the ecliptic; the sun would be vertical during all the year at the equator, and would shine from pole to pole. Days would be of uniform length; the meridian altitudes of the sun at any place of observation would always be the same; the heat received by any part of the earth would only vary from day to day, in accordance with the varying distance from the earth to the sun. Alternations of heat and cold, summer and winter, seed-time and harvest, would cease, and the productiveness of the earth would be greatly diminished, or destroyed.

216. **If the earth's axis lay in** the plane of its orbit, and, as now, should point constantly in one direction, the changes would be those we now observe, but vastly exaggerated. The equinoctial would be at right angles with the ecliptic; the sun would be vertical in turn over every part

of the earth. At one season he would shine directly on the north pole, and his scorching rays, pouring down day after day, with no intervening night, would produce a degree of heat more intense than any which the earth now knows. Six months later the entire northern hemisphere, to the very equator, would be plunged into continuous night, while the cold would be as intense as the heat had been. No part of the earth would be free from these extreme vicissitudes of heat and cold, and no life, vegetable or animal, such as now exists, could endure such changes.

217. **The position of the axis.** — The ecliptic makes with the equinoctial an angle of 23° 27′ (58). The axis of the earth is, therefore, inclined from a perpendicular by the same amount, or makes an angle with the plane of the ecliptic of 66° 33′. The axis is always turned toward the same point of the far distant sky. It is always parallel to itself.

DAY CIRCLE.

218. Suppose a plane to pass through the center of the earth, perpendicular to the direction of sunlight. It will divide the earth into two hemispheres, one turned toward the sun, and illuminated, the other turned away, and in darkness. On one side of the circle is day, on the other side, night; we may call it the day-and-night circle, or, briefly, the *day circle*. This circle may be conceived to accompany the earth in its annual revolution, the light side always toward the sun. The earth may be conceived to rotate beneath, or within this circle; when any point passes from the dark to the bright side, the sun rises for that point; when the same point passes again under the circle, the sun sets. A globe fitted with a circle of this kind is very convenient for illustration.

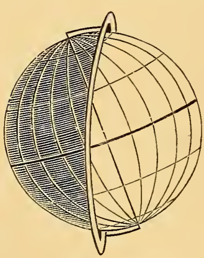

Fig. 72.

219. The Tropic of Cancer.—At the summer solstice (56), on the 20th of June, the earth is near the southern point of its orbit, its north pole inclines toward the sun, and the sun's rays fall vertically 23½° north of the equator. The sun's northern declination has been increasing day by day (136) up to this time, and from this day will decrease; the

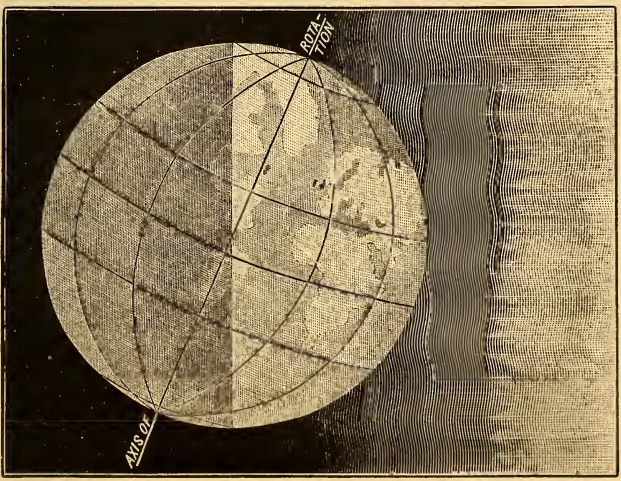

Fig. 73.

sun seems to turn and go back to the equator. The parallel of 23½° is called a *tropic*,* and, because the sun is in that part of the ecliptic called the sign Cancer, it is the Tropic of Cancer. It marks the greatest distance north of the equator at which the sun's rays are vertical on any day of the year.

220. The Polar Circle.—The day circle, being always perpendicular to the plane of the earth's orbit, is 23½°

* Τροπικός, *tropikos*, turning.

from either pole. A person $23\frac{1}{2}°$ from the north pole may make an entire revolution about the pole, as the earth rotates, without passing beyond the day circle; for him the sun does not set. The circle of latitude farthest from the pole at which the sun does not set on the longest day of the year is *a polar*

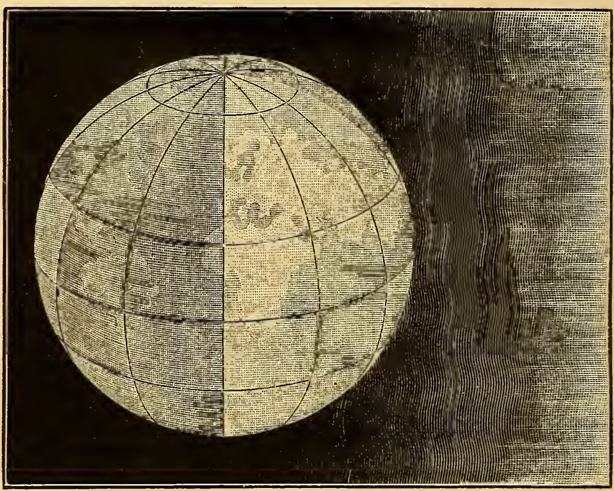

Fig. 74.

circle. On the same day, a person $23\frac{1}{2}°$ from the south pole may make one entire revolution about the pole without seeing the sun rise.

221. The season.—At this time, in the northern hemisphere, the sun's rays fall most directly, and the days are longer than the nights; heat is most abundant, and the season is summer. In the southern hemisphere, the sun's rays fall obliquely; the nights are longer than the days; heat is least abundant, and the season is winter.

222. The winter solstice.—On the 22d of December, the earth reaches the northern place in its orbit, the sun has

its greatest southern declination, and all the preceding conditions are reversed. The sun's rays are vertical 23½° south of the equator, at the *Tropic of Capricorn*. The day circle is removed 23½° beyond the south pole, forming the *south polar circle*, at which the sun for that day does not set; at the north polar circle, the sun does not rise. It is summer in the southern hemisphere, winter in the northern.

As both the summer and the winter solstice find summer on some part of the world, it might be better to call the first the *northern*, the second the *southern*, solstice.

The north polar circle is also called the Arctic circle; the south polar circle, the Antarctic circle.

223. At the equinoxes (55), the earth's axis is inclined neither toward nor from the sun. The day circle passes through the poles; the sun is vertical over the equator; the day is equal to the night; the sun's rays are equally oblique in each hemisphere. It is spring on that side of the equator toward which the sun is moving; autumn, on that side from which he is departing.

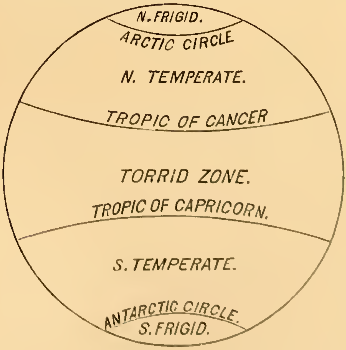

Fig. 75.

224. Zones.—The tropics and polar circles divide the earth's surface into five belts, called zones. The *torrid zone* lies on either side of the equator, between the tropics; it includes all that part of the earth on which the sun's rays are at any time vertical. The *frigid zones* lie between the polar circles and the poles; they include those portions of the earth on which the sun does not shine on some day of the year. The *temperate zones* lie between the tropics and the

polar circles; in these parts of the earth, the sun's rays are never vertical, and from them the sunlight is never excluded during a whole day.

The breadth of the torrid zone, and of each frigid zone, is 47°; each temperate zone is 43° wide.

SUMMER HEAT.

225. First cause of summer heat.—In summer the sun's rays are most nearly perpendicular to the earth's surface. The heat which falls perpendicularly on the surface

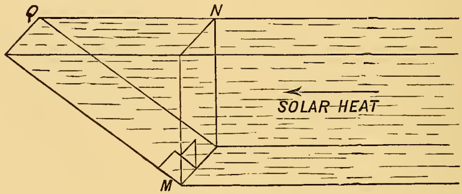

Fig. 76.

MN is distributed over a space smaller than the surface *MQ*, to which the same heat comes obliquely; the quantity received by a unit of surface at *MN*, is, therefore, greater than the quantity received by a like unit at *MQ*.

226. Second Cause.—The earth constantly gives out heat by radiation; it receives solar heat at any place only when the sun is above the horizon of that place. The heat received during twenty-four hours is greater as the duration of sunshine is greater; hence, any place on the earth receives most heat during the long days of summer, and least during the short days of winter. When the heat received during twenty-four hours is more than that radiated during the same time, the place becomes gradually warmer; when the heat is less than that radiated, it becomes cooler.

227. The maximum of heat is not at the time of the summer solstice. At that time, the sun's rays are most nearly vertical in the northern hemisphere; the daily income of heat is largest; and, although the daily expenditure by radiation is largest, their difference, or the net increase for one day, is also largest. On succeeding days, the income, though not as great for one day, is still more than the expenditure, and the aggregate increases. This will continue until the maximum of heat for the season is reached, when the loss becomes equal to the gain by day, and begins to exceed it. The maximum of heat occurs when the sun's declination after the solstice is about 12° north; the maximum of cold, when the declination is 12° south. Hence, the heat of summer begins to decrease about the 20th of August; the cold of winter abates soon after the 16th of February.

For like reasons, the warmest part of the day is about 2 o'clock P. M.; the coldest time of night is shortly before sunrise.

228. In the southern hemisphere, all these results are reversed. It must be remembered that the reasoning applies to the hemispheres as wholes, leaving out of consideration the modifying influences of oceans, continental forms, and mountain ranges.

SIGNS OF THE ECLIPTIC.

229. In the early days of astronomy, the ecliptic was divided into twelve parts, of 30° each, called *signs*: each sign was named from the group of stars which was most prominent near it. The signs in order, beginning at the vernal equinox, were named Aries, Taurus, Gemini; Cancer, Leo, Virgo; Libra, Scorpio, Sagittarius; Capricornus, Aquarius, and Pisces. The vernal equinox was at the first point

in Aries, and was indicated by the symbol ♈. The equinoxes move westward along the ecliptic about 50″ annually; this motion is called the *precession of the equinoxes* (App. V). The vernal equinox is now in the *constellation* Pisces; but, as the names of the signs remain unchanged, it is still the first point of the *sign* Aries.

230. The length of the seasons.—The sun is said to enter a certain sign when the opposite sign comes to the meridian at midnight. The sun enters Aries at the vernal

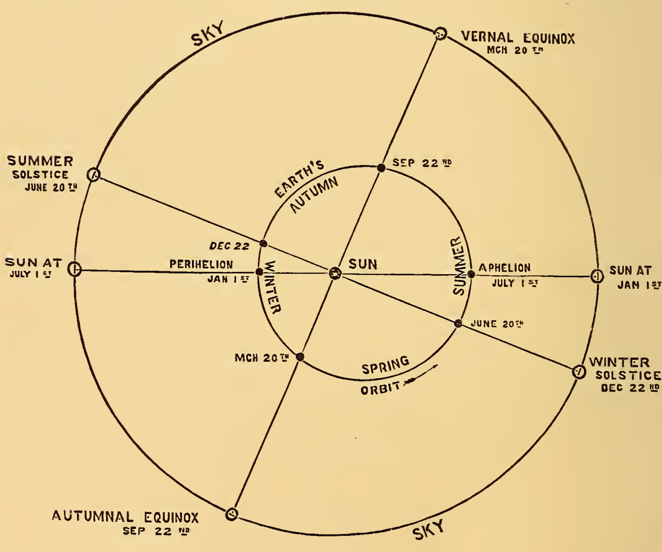

Fig. 77.

equinox; Cancer, at the summer solstice; Libra, at the autumnal equinox; Capricornus, at the winter solstice. But the motion of the earth over different parts of its orbit is not uniform (200); hence the apparent motion of the sun among the signs varies, and the seasons are of unequal length.

From Aries to Cancer,	Spring,	92.9	days	} 186½
" Cancer to Libra,	Summer,	93.6	"	
" Libra to Capricornus,	Autumn,	89.75	"	} 178¾
" Capricornus to Aries,	Winter,	89.	"	

Spring and summer are together 7¾ days longer than autumn and winter.

231. Gradual changes in the length of seasons.—The line of apsides (210) moves slowly to the eastward, about 12″ a year; the equinoxes move westward about 50″ annually; the distance between perihelion and vernal equinox increases, therefore, about 62″, or more than 1′ yearly. Perihelion is* in the 11th degree of Cancer, in longitude 100° 56′; about $60 \times 100 = 6000$ years ago, perihelion must have coincided with vernal equinox; spring was shorter than summer; but spring and summer were together equal to autumn and winter. About 11,000 years since, perihelion was near summer solstice; the earth being nearest the sun in June, both summer's heat and winter's cold must have been more intense than now, in the northern hemisphere.

232. It is ascertained that the eccentricity (208) of the earth's orbit is diminishing gradually, the curve becoming more nearly circular. Leverrier estimates that 80,000 years ago the eccentricity must have been about three times the present amount, and that the solar heat in winter was so reduced by this cause, that the average winter temperature, instead of 39° F., as now, was between 6° and 23° below the freezing point.

EQUATION OF TIME.

233. Definition.—In algebra, an equation is an expression of the equality of two quantities. In astronomy, an equation

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*Jan. 1, 1885.

is something which must be added to, or subtracted from, another quantity to bring it to a definite standard. It does not show that two quantities are equal, but rather what must be applied to one to make it equal the other. This use of the word may be illustrated by quotations of bank stock. If a share whose par value is $100 is sold for $98, the equation is $2, as that amount added to the price obtained will restore the par, or standard, value. If the same share sells for $104, the equation is—$4, for the same reason.

234. **Sidereal time** has no equation, because the length of a sidereal day is invariably 23 h. 56 m. 4.09 sec. mean solar time (100).

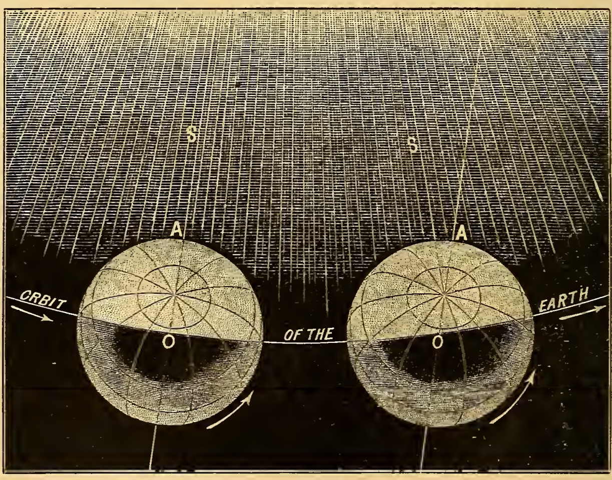


Fig. 78.

235. **Circumstances which would give no equation of solar time.**—1. If the sun appeared stationary in the heavens like a star, solar time would not differ from sidereal time.

2. When the meridian of a place has come, by the rotation of the earth, to the place on the sky which it had at that time on the preceding day, the sun is no longer there, but has moved eastward, and the meridian must go on farther to overtake the sun. This is the apparent statement; the fact is, that the forward motion of the earth in its orbit has to be provided for by an equal movement of the meridian. During the day, the earth has moved in its orbit from O to O'. As the meridian comes to the position A, parallel to its position of the day before, it has made a sidereal revolution, since it points to the same place on the sky, but it must go on to the line $O'S$, to be opposite the sun.

If the sun's motion among the stars were *uniform*, and were *on the equinoctial*, so that his daily change in right ascension were the same, there would be no equation of time. The solar day would be equal to the invariable sidereal day, increased by the uniform time required for the meridian to overtake the sun in right ascension.

236. **Mean solar time.**—In four sidereal years there are very nearly 1461 days, or in one year 365¼ days. A clock which has indicated 365¼ days, of 24 hours each, in one year, has kept mean solar time (97). Twenty-four hours by this clock is a mean solar day. At certain times in the year, the time from noon to noon is about 8 seconds less than 24 hours of mean solar time, and at other times about 24 seconds more. These differences accumulating day by day soon amount to an aggregate which is considerable.

237. **Equation of time.**—At 12 by the clock, the sun may have already passed the meridian, and is said to be fast of the clock; it may not yet have come to the meridian, and is slow of the clock. The difference in time between apparent noon, as shown by the passage of the sun over the meridian, and mean noon, as shown by the clock, on any day of the year, is the *equation of time* for that day.

CAUSES OF EQUATION.

238. **The causes** which produce this variation in time are two:

1. The unequal apparent motion of the sun on the ecliptic, caused by the unequal real motion of the earth in its orbit.

2. The variable inclination of this motion from day to day to the equinoctial.

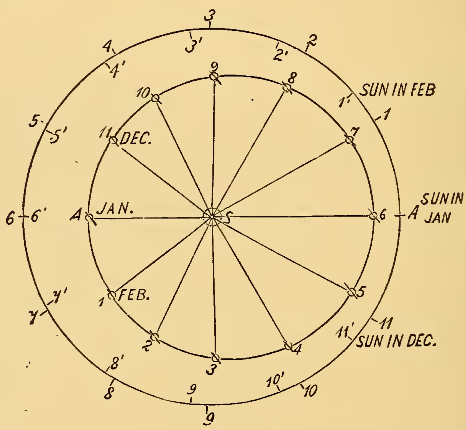


Fig. 79.

239. **First cause.**—The earth's angular motion (194) is fastest when the earth is nearest the sun; that is, from September to March, the greatest rate being on the 1st of January. On that day, the earth makes more than its average angular progress, and therefore the sun makes more than his average apparent day's journey on the ecliptic. Hence, when the meridian is about to pass the sun on the next day, it finds that the sun has moved to the eastward of his position on the day before by an amount greater than the average,

and, therefore, more time will be required for the meridian to overtake him. The sun is, accordingly, slow of the clock about 8 seconds on this account. The same result occurs on the next day, and the sun is now 16 seconds slow. The difference will continue to increase daily until soon after the vernal equinox, when the earth moves at its average rate.

240. **After equinox.** — From the vernal equinox until apogee, the rate of the earth's angular motion is less than the average, and is constantly decreasing; the daily easting of the sun diminishes at the same rate. The length of the solar day, although still more than 24 hours of mean solar time, becomes gradually less, until the accumulated difference is entirely lost on the 1st of July, and the sun and clock, so far as this cause is concerned, come together again. After July 1st, the sun becomes fast of the clock, as the sun's daily motion is less, and the meridian comes up with the sun in less than the average time; the action of the preceding half year is reversed.

241. **Second cause.**—Were the sun's motion in longitude uniform, there would still be an equation of time. Difference in time is caused by difference in right ascension (106), but a uniform amount of motion in celestial longitude, produces a variable amount of motion in right ascension. Let AC represent part of the equinoctial and BD a part of the ecliptic crossing the equinoctial at E. Suppose that in one day the sun has moved from E to D; his difference of right ascension will be EC, less than ED, because the base of a right-angled triangle is less than the hypotenuse. The sun is not so far to the east as his motion would indicate; the meridian overtakes him sooner, and the day is shorter by this cause. The sun is fast of the clock.

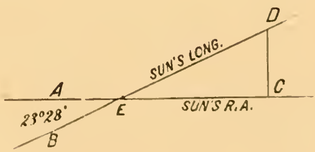


Fig. 80.

At the solstices the path of the sun is nearly parallel to the equinoctial, but is removed from it 23½°. The right ascension AB being reckoned on the equinoctial is more than the actual distance traversed by the sun; the sun's relative easting is increased; the day is longer; the sun is slow of the clock.

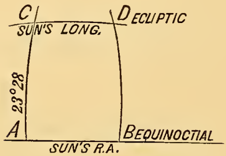


Fig. 81.

242. The equation for the day is found by combining the results obtained for each cause separately. Thus, on April 4, the sun is slow from the first cause 7 m. 40 sec.; from the second, fast 4 m. 46 sec.; the equation is, therefore, $+(7\ 40) - (4\ 46) = +(2\ 54)$; when the sun is on the meridian, the clock should show 2 minutes 54 seconds *past twelve.*

243. Morning and afternoon unequal.—Sunrise and sunset are equally distant from apparent noon; hence, if mean noon is, say, 7 minutes later than apparent noon, the clock adds 7 minutes to the morning, and subtracts it from the afternoon; the morning is 14 minutes longest. Sunrise and sunset will be as much slow or fast of the clock as midday.

244. Table of equation of time.—The values of the equation for each day in the year have been computed, and are arranged in a table at the end of the book. It is more important that a watch should agree with a recognized standard, than that it should be absolutely correct. It is useless, however, to attempt to regulate a watch by a sundial, or by a noon mark, without correction for equation of time. To say that a watch runs with the sun, is to say that it is a poor time-keeper.

THE CALENDAR.

245. The tropical year.—The *sidereal year* is the time occupied by the earth in passing once round its orbit, or

until it has brought the sun back to the same star in the heavens. Its length is 365 d. 6 h. 9 m. 9.6 sec. But the vernal equinox has a motion backward along the orbit, amounting to 50″ of arc per annum; the earth, therefore, comes back to the vernal equinox a little sooner than to the precise place it started from a year before, as shown by the stars. The time required by the earth to return to the vernal equinox is called the *tropical year;* its length is 365 d. 5 h. 48 m. 46.05 sec. This is the year employed in the calendar; it is 20 m. 23.55 sec. *less* than the sidereal year.

The time required by the earth to return to perihelion is the *anomalistic* year. It is 365 d. 6 h. 13 m. 49.3 sec. It will be remembered that perihelion moves forward about 12″ annually (231); hence, its year must be *longer* than the sidereal year.

246. The Julian Calendar.—For practical purposes, it is convenient to consider some number of whole days a year. The Greek year had at different times 354, 360, and 365 days. The Roman year, under Numa, had 355 days. There was a continual discordance between the civil year and the astronomical year, which reached such a degree that the autumn festivals were celebrated in the spring, and those of harvest, in midwinter. An extra month, called Mercedonius, was added every second year. The length of this month was not fixed, but was arranged from time to time by the pontiffs, and this gave rise to serious corruption and fraud, interfering with the duration of office and the collection of debts.

In the year 46, B. C., Julius Cæsar reformed the calendar. To restore the seasons to their proper months, he made that year contain 445 days. Assuming the astronomical year to be 365¼ days, he made each fourth year to contain 366 days; the remainder, 365. The added day was placed in the month of February. The 24th of February, called *sexto-calendas*, being the sixth before the calends, or 1st of March, was celebrated in honor of the expulsion of the kings; the

additional day was placed next to this feast, and was called *Bis-sexto-calendas*, whence our name *Bissextile*.

247. **The Gregorian Calendar.** — The astronomical year, as assumed by Cæsar, was too long by 11 m. 13.95 sec., or about 3 days in 400 years. By the year A. D. 1582, the error had grown to 10 days. So many days had been wrongly reckoned into the years that were gone, and, therefore, the dates were 10 days behind what they should have been. To correct this error, Pope Gregory XIII ordered that the 5th of October of that year should be called the 15th, and the order was forthwith obeyed in all Roman Catholic countries. It was also arranged that three intercalary days should be omitted in four centuries, or one in each centenary year except the fourth. Hence, the years which have 366 days are, first, those whose numbers are exactly divisible by 4, and not by 100; second, those whose numbers are divisible by 400, and not by 4000.

The Gregorian calendar was introduced into England and her colonies in 1752, the error being then 11 days. Dates previous to the change are sometimes referred to as O. S., Old Style; occasionally, dates are given with reference to both styles. Washington's Birthday was February 11/22; the 11th of February, O. S., or 22d of February, N. S.

The Gregorian calendar is used in all Christian countries, except Russia. The error in the Julian calendar is now 12 days.

248. RECAPITULATION.

As the sun's parallax must be less than 20″, the sun is, in *diameter* more than 48 times, in *volume* more than 110,000 times, as large as the earth. Being so much larger, the sun must be at rest, rather than the earth.

The *earth's orbit*, found from the apparent size and angular motion of the sun, is an *ellipse*.

Kepler's Laws:

First; Each planet revolves about the sun in an elliptical orbit, the sun being at one focus.

Second; The velocity of a planet is such that the line drawn from the sun to the planet sweeps over equal areas in equal times.

A *single impulse of projection* and a *constant attraction toward a center* are enough to cause motion along the curve of an ellipse.

Change of seasons is due, not to the varying distance of the sun, but to the *angle made by the earth's axis with the plane of its orbit.*

Tropics are at the *greatest distance* from the *equator* at which the *sun's rays fall vertically.*

Polar circles are at the *greatest distance* from the *poles* at which the *sun does not set during twenty-four hours once in a year.*

The *heat* at any place is *greatest in summer*, because the surface of the earth is then in position to receive the greatest number of heat-rays; and because more heat is received daily than is radiated.

Equation of time is required on account of the *variable apparent motion* of the sun along the ecliptic, and the *variable inclination* of that motion to the *equinoctial.*

<table>
<tr><td>In a Sidereal year,</td><td rowspan="3">the earth returns to</td><td>the same star.</td></tr>
<tr><td>Anomalistic,</td><td>the perihelion.</td></tr>
<tr><td>Tropical or Calendar,</td><td>the vernal equinox.</td></tr>
</table>

CHAPTER XI.

PLANETARY MOTIONS.

249. In the preceding chapters, we have learned:

The sun's distance from the earth is very great; how great we can determine only when we know its horizontal parallax.

The sun is very much larger than the earth.

The distance from the earth to the sun is not uniform, but the variations in distance, and in both real and angular motion, are regular.

The moon is comparatively near the earth; its distance is variable; its mean distance and the amount of its variations are known. In the sky it appears as large as the sun; in fact, it is smaller than the earth.

250. Planets.—When a star does not pass the meridian at regular intervals of a star-day, we know that it has a motion of its own in the sky. Ancient astronomers recognized five such bodies, besides the sun and moon: they called them *planets* (117). They named them after their gods, Mercury, Venus, Mars, Jupiter, and Saturn. Modern astronomy has added many others to the list.

Their motions are apparently irregular. Generally they move from day to day toward the east; sometimes they are stationary, and at times they move westward. The apparent motion of a planet toward the east is said to be *direct;* that toward the west is *retrograde.*

251. The Zodiac.—When the successive positions of the planets are marked upon the celestial globe, they are found in very regular paths among the stars not far from the ecliptic. The ancients observed that these movements are included in a narrow belt extending eight degrees on either side of the ecliptic; this belt they called the *Zodiac.* The zodiac, like the ecliptic, was divided into 12 parts, called signs (229).

VENUS.

252. The evening and morning star. — At certain seasons, a brilliant star appears in the south-west soon after sunset; this star the Greeks called Hesperus; we call it *the evening star.* Gradually, night by night, it departs from the sun. When it has gone about 45°, it remains for a few nights nearly stationary; then it returns, and disappears.

Soon after the departure of the evening star, a bright star is seen in the south-east, a little before sunrise. It is Lucifer, *the morning star.* Like the evening star, it goes from the sun about 45°, then returns and disappears. Thus, for more than 3000 years, have the alternations of these stars been recorded; they never appear on the same day, and are always seen on opposite sides of the sun. They are evidently the same body that revolves regularly about the sun: it is the planet Venus.

253. Venus in the telescope.—The rays, which to the naked eye surround the star, vanish in the telescope, and we see a disc with phases like the moon. When near the sun, it shows first a small, round disc; as it departs, the disc grows larger, but a portion seems to be removed from the side farthest from the sun; at the greatest distance, the bright part is a semicircle; while it returns, the disc grows narrower and larger, day by day, until just before it disappears it shows a fine narrow crescent, the points or horns turned away from the sun. The morning star reverses these appearances.

There is first the fine crescent, as if cut from a large circle, lastly, the full circle of small diameter.

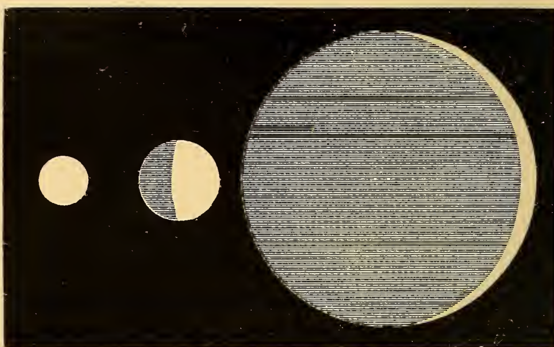


Fig. 82.

254. Transits.—When the planet is near the sun, it vanishes in the bright sunshine; sometimes between its disappearance as evening star, and its reappearance as morning star, it is seen to cross the sun's disc during the day, as a round, black spot. This passage before the sun is called a *transit*.

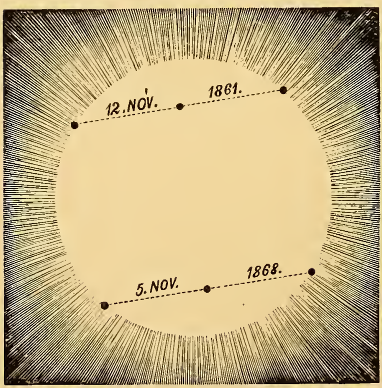


Fig. 83.—Transits of Mercury.

255. Mercury.—Another planet, still nearer the sun, exhibits the same series of changes. It appears in the evening, soon after sunset, at a distance of about 25°, and vanishes; it afterward appears again in the morning; it exhibits phases, and some-

times makes a transit. Its variations are not as great as those of Venus, and its changes are completed in less time: its name is Mercury.

256. **Inferences.**—All the movements of these bodies will be easily understood, if we suppose that these planets are opaque bodies, which reflect light from the sun and revolve in regular orbits about it. The orbit of Mercury is within that of Venus, and both are within the orbit of the earth. Tycho Brahe believed that they revolve about the sun, but thought that they accompany the sun in its revolution about the earth.

MARS.

257. A bright red star, called Mars, appears at times in the east about sunset, crossing the meridian near midnight. He is in the part of the sky opposite to the sun. In a few months he journeys among the stars until he sets with the sun; then he continues his round until he appears again in the east at sunset. He is never seen to pass between the sun and the earth. In the telescope, he never shows the fine crescent which is shown by Mercury and Venus. Although in the same part of the sky, he is evidently beyond the sun, and his path encircles both the earth and the sun. His diameter is greatest when he is opposite the sun; it is then about 23″; it is least when in the same quarter of the sky as the sun; it is then about 4″. But his distance from the earth must vary inversely as his apparent diameter (182), and therefore his distance when he is nearest is to his distance when most remote as 4 to 23. The sun is evidently much nearer than the earth to the center of his orbit; it is more likely, moreover, that he revolves about the sun, than about the earth, as the sun is by far the larger and more powerful of the two.

258. **Retrograde motion.**—The general motion of all the planets among the stars is eastward, or direct; when

they come into the quarter of the sky which is opposite the sun, their motion is westward, or retrograde. If the earth were the center of their motions, we must suppose that the planets actually return and retrace part of their course. Ancient astronomers recognized this fact, and evaded this conclusion by supposing that the planets move about the sun, and with it about the earth, describing very complicated curves, called epicycles, such as might be made by a nail in the rim of a wheel as it rolls about the rim of another wheel. This opinion was generally adopted by philosophers, and Milton refers to it when he speaks of the heavens as

> "With centric and eccentric scribbled o'er,
> Cycle and epicycle, orb in orb."

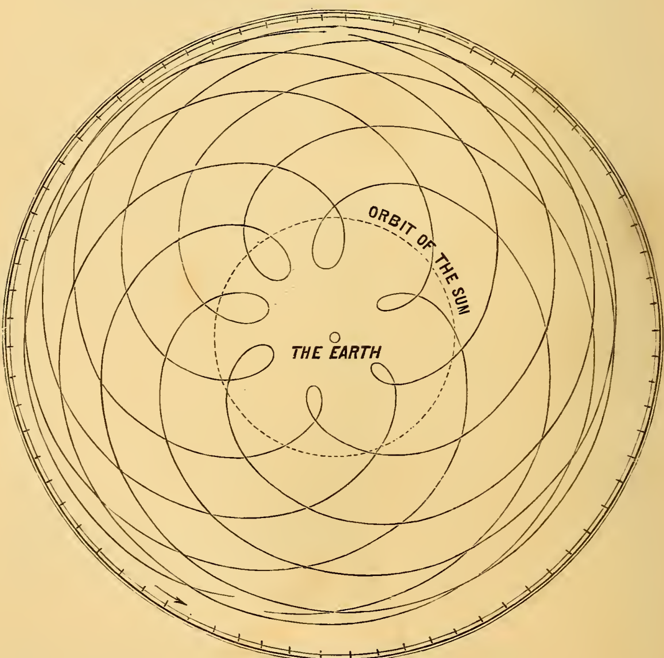


Fig. 84.

Figure 84 shows the supposed path of Mars, from 1708 to 1723, as drawn by Cassini. The earth is supposed to be in the center, while the dotted line shows the path of the sun.

THE COPERNICAN SYSTEM.

259. Aristarchus of Samos, 280 B. C., and Cleanthes of Assos, 260 B. C., suggested that the earth with the other planets revolves about the sun, but their opinions were so different from the doctrines commonly held, that they were

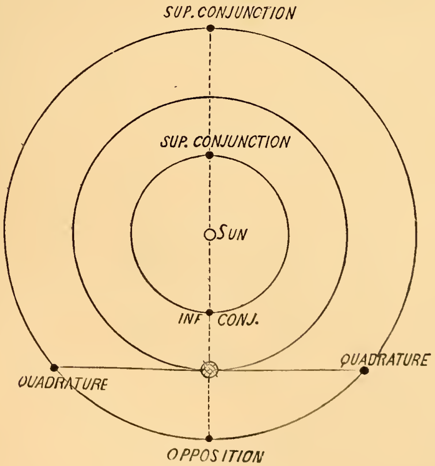


Fig. 85.

accused of impiety. In 1543, the ideas of the Pythagorean philosopher, Philolaus, were revived by Copernicus, a Prussian. About sixty years later, Galileo was forced to retract his statement of the same truths. It remained for Kepler, in 1619, to establish the true theory of the planetary system, by discovering that the planets, in their motions, obey the laws which bear his name.

260. The true solar system.— Since the discoveries of Kepler, the sun has been recognized as the central body about which the planets revolve in elliptical orbits, nearly circular. The planets, in their order from the sun, are Mercury, Venus, the Earth, Mars, the Minor Planets, Jupiter, Saturn, Uranus, Neptune. Those within the orbit of the earth, Mercury and Venus, are *inferior* planets. Those without the orbit of the earth are *superior* planets.

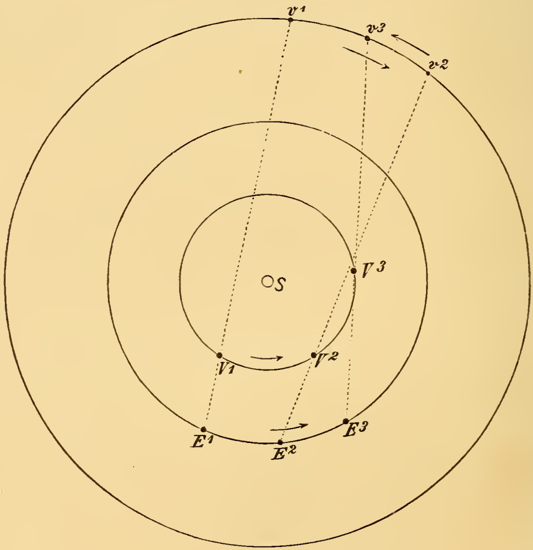


Fig. 86.

261. Conjunction and opposition.—Two bodies are in conjunction in the sky (Fig. 85), when they have the same celestial longitude (119). The bodies in conjunction are evidently on the same side of the earth. If they are the sun and a planet, the conjunction is called *inferior* when the planet is between the earth and the sun; *superior*, when the planet is beyond the sun. Two bodies are in

opposition when their difference in celestial longitude is 180°; they are in opposite parts of the sky, and in opposite directions from the earth.

A planet is in *quadrature* when its position in the heavens is 90° from the sun. The positions, conjunction, opposition, and quadrature, are sometimes called the *aspects* of the planets. The astrologers added several others to the list.

APPARENT MOTION EXPLAINED.

262. Inferior planets. — Let the outer circle in figure 86 represent the sky, and the inner circles the paths of

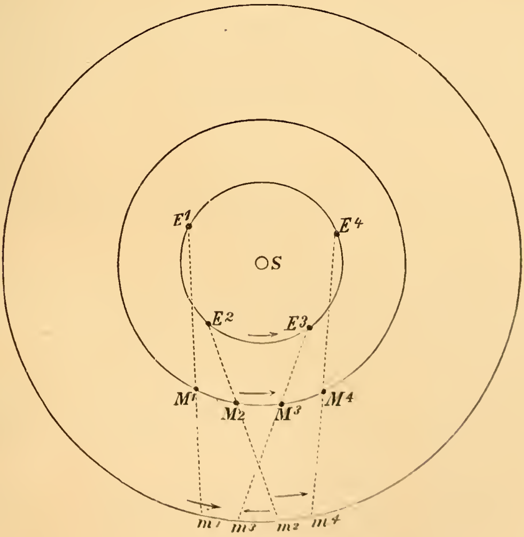


Fig. 87.

Venus and the earth, their successive positions being shown by the figures 1, 2, 3. When the two bodies are in the places marked 1, Venus appears at v^1 on the sky; when

they have moved to the places marked 2, Venus seems to have gone back to v^2, or to have *retrograded;* when they are at 3, Venus appears to have gone *forward* to v^3, and so on. Evidently, at some place between V^2 and V^3, Venus moves a little way on a line directly away from the earth, and therefore she seems stationary on the sky.

263. **Superior planets.**—Let the inner circles of figure 87 now represent the orbits of the earth and Mars, the positions being shown as before. While the earth and Mars are moving regularly to the positions 2, 3, and 4, Mars appears in the sky to go forward to m^2, backward to m^3, and, finally, forward to m^4. In the vicinity of m^2 and m^3, there are places where the planet seems to be at rest, when changing its apparent motion from direct to retrograde, and back again. Thus the Copernican theory of the solar system explains easily and simply all the apparently erratic and complicated motions of the planets.

THE TIMES OF THE PLANETARY REVOLUTIONS.

264. **Sidereal revolution.** — The time occupied by a planet in passing once round the sun is the time of its *sidereal revolution.* If seen from the center of the sun, the planet would return in that time from one star on the sky to the same star again. A sidereal revolution can not be observed from the earth, since the earth is in motion; its length can be found only by computation.

265. **Synodic revolution.** — A synodic revolution is completed when the three bodies,—the planet, the earth, and the sun,—come again into the same relative position, as, into conjunction or opposition. Let the circles represent the orbits of Jupiter and the earth. Suppose the planets are in conjunction on the line *SEJ*, starting evenly together in their race about the sun. When the earth has completed

one revolution, and has come back to the line SJ, Jupiter is not there, and the earth overtakes him somewhat farther on, in the line $SE'J'$. The two bodies have completed one *synodic* revolution;* the time is that between two successive conjunctions of the same bodies.

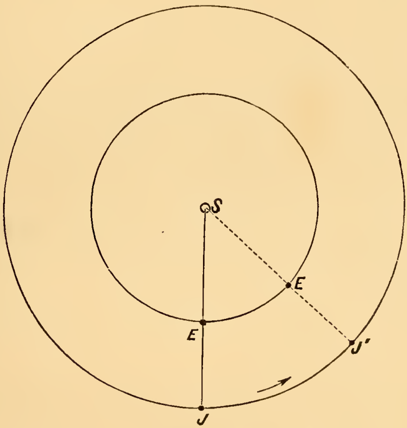


Fig. 88.

266. To find the time of a sidereal revolution of Jupiter.—During one synodic revolution, the earth has passed over its entire orbit and the arc EE', opposite the angle ESE'; Jupiter has passed over the arc JJ', also opposite the angle ESE', and therefore containing as many degrees as EE'. By observation, the time of Jupiter's synodic revolution is 398.8 days. The earth went from E to E again in 365.26 days, and therefore passed the space EE' in $398.8 - 365.26 = 33.54$ days. As the earth describes 360° in 365.26 days, it passes $360° \div 365.26$, or 0.9856°, in one day; and as it had been moving 33.54 days

* Σύνοδος, *sunodos*, coming together. Hence, *synod*, an assemblage.

at that rate, it had passed over $33.54 \times 0.9856° = 33.06° =$ the angle described by Jupiter in one synodic revolution. But evidently,

Ang. of Syn. Revolution : Whole Revolution : :
Time of Syn. Rev. : Time of Sidereal Rev.

$$33.06° : 360° :: 398.8 \text{ days} : 4342 \text{ days}.$$

Hence, Jupiter's year equals about 4342 of our days, or nearly 12 of our years.

267. Sidereal revolution of Venus.—This is found as before, except that Venus is the inner of the two planets. The time of synodic revolution is 584 days. In this time, the earth has described $584 \times 0.9856° = 575.6°$. But Venus has made one circuit *more* than the earth, and has, therefore, described $575.6° + 360° = 935.6°$, in 584 days. Then, as before,

$$935.6° : 360° :: 584 \text{ days} : 224.7 \text{ days},$$

the length of Venus's year.

A table of synodic revolutions will be found on page 141, and pupils should find the length of year for the other planets from the data there given. The results will not agree strictly with those of the table; first, because they are found as if the orbits were circular, and the motions uniform; second, the data are in days, neglecting fractions of a day.

268. A more accurate method.—On the 7th of November, 1631, M. Cassini observed a transit of Mercury; the time of conjunction was 7 h. 50 m., A. M., mean time, at Paris, and the longitude of Mercury, 44° 41′ 35″. Another conjunction was observed in 1723, November 9, at 5 h. 29 m., P. M., the longitude being 46° 47′ 20″. The time which had elapsed was 92 y. 2 d. 9 h. 39 m. Adding 22 days for the leap-years in that time, and reducing, we have 33604.402 days. During that time, Mercury had made 382 revolutions and 2° 5′ 45″ more. In 33604.402 days, Mercury had described 137522.09583 degrees, or 4.09234 degrees in one

day. This, then, is the average daily rate of Mercury for a period of nearly 100 years. We have, then,

360 ÷ 4.09234 = 87.9692 days, = 87 d. 23 h. 15 m. 57 sec., the exact length of Mercury's year.

DISTANCES OF THE PLANETS FROM THE SUN.

269. **Unit of measure.**—We measure length by comparison. A piece of cloth we compare* a certain number of times with a rod whose length we call a yard. The distance between two cities we measure with a length which we call a mile. Even if the yard-stick were lost, we might measure the cloth with any rod which we happen to have, and afterward, when we have compared our rod with a yard measure, reduce the length of our cloth to yards. The measuring-rod with which we obtain the planetary distances is the radius of the earth's orbit, although we have not yet found the length of this rod. We compare other distances with this, and by this means we may be able indirectly to find the length of this quantity, which we could not determine directly (190). When that is found, our results may be changed from one denomination to the other, —from radii of the earth's orbit to miles.

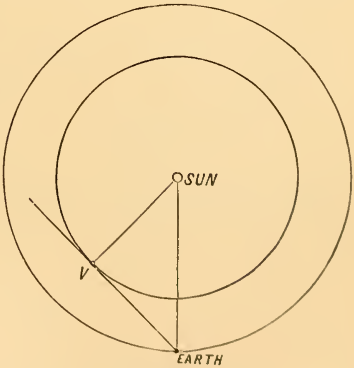


Fig. 89.

270. **Distance of an inferior planet—Elongation.**—The elongation of a planet is its angular distance from the

* *Con-paro*, to make equal with.

sun. Let E represent the earth, and V an inferior planet, as Venus. (Fig. 89). When EV is tangent to the planet's orbit, the angle of elongation, VES, is evidently greatest for that revolution of Venus. In the triangle VES, the angle E is known, V is a right angle, and SE is the radius of the earth's orbit, our unit of measure. The value of VS, found by the methods of plane trigonometry, is some fractional part of that unit.

271. Orbits not circular.—At different times the greatest elongations vary, as shown in the table. From this it appears that the radii of the orbits vary in length; the data show that the orbit of Mercury has considerable eccentricity, while that of Venus is not circular. A series of calculations, using both the varied elongations, and the different radii of the earth's orbit, as found at the time of observation, would give plans of the orbits very nearly.

	Mercury.	Venus.
Least extreme elongation,	17° 37′	44° 58′
Greatest " "	28 4	47 30
Mean " "	22 46	46 20
Mean radius,	0.387098	0.723332

272. Distance of a superior planet.—Let S, E', and M' represent respectively the sun, the earth, and a superior

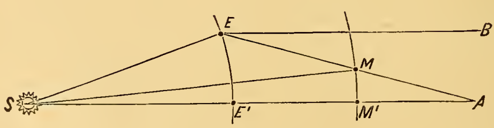


Fig. 90.

planet, as Mars, on the day when the planet is in opposition (261). Mars appears in the sky in the line $E'M'A$. On the day after opposition, the earth has moved to E, and

Mars to M; the angles ESA and MSA are easily found from the known rates of the planets. Because of the great distance of the sky, a fixed star, which, on the first day, was seen in the line $E'A$, now appears in the same direction on the parallel line EB, while Mars seems to have moved backward from the star by the amount of the angle AEB. This angle is easily observed: as EB and SA are parallel, it is equal to EAS.

In the triangle ESM, we have ES, the radius of the earth's orbit;

$$SEM = 180° - (ESA + AEB), \text{ (Geom. 255)};$$
$$ESM = ESA - MSA;$$
$$EMS = EAS + MSA, \text{ (Geom. 261)};$$

A trigonometrical solution gives the side MS, which is desired.

273. Table of Planetary Revolutions.—

Name.	Relative Distance.	Synod. Rev.	Sid. Rev. Days.	Sid. Rev.
Mercury,	0.387099	115.9	87.97	3 mos.
Venus,	0.723332	583.9	224.70	7½ "
Earth,	1.		365.26	1 year.
Mars,	1.523691	779.8	686.98	23 mos.
Jupiter,	5.202800	398.8	4332.58	12 yrs.
Saturn,	9.538852	378.0	10759.22	29½ "
Uranus,	19.18338	369.7	30686.82	84 "
Neptune,	30.05437	367.5	60126.71	165 "

KEPLER'S THIRD LAW.

274. After comparing in various ways the times of the planets and their distances, Kepler discovered his third law of planetary motion:

The squares of the times are in proportion to the cubes of the mean distances from the sun.

This most remarkable law, applying as it does to all the planets in their circuits about the sun; to the satellites, as they revolve about their primaries; even to the members of the far-off stellar systems in the remote regions of the universe, proves that all these objects have a similar origin and are subject to the same government. Nature works with uniformity in all her vast domain.

This law is practically useful in determining the mean distance of a newly-discovered planet. The rate of motion of the stranger would be first observed; from this its time of revolution is computed, and its distance obtained. Thus, if a planet were found whose period is 5 years,

$$1^2 : 5^2 :: 1^3 : x^3 \therefore x = \sqrt[3]{25} = 2.924+.$$

The distance of the planet from the sun would be 2.924 times the mean radius of the earth's orbit.

Distances obtained by Kepler's third law are deemed more reliable than those derived from other sources.

275. Actual distances not yet found.—As yet we have found only the *relative* distances of the planets, when compared with the distance of the earth from the sun, taken as a unit of measure. One of these distances positively known, would help as to all the rest. When Mars is nearest the earth, his distance from the sun is about one and one half, and, therefore, his distance from the earth is about one half, the distance from the earth to the sun. When so near, his parallax may be found.

276. Observations of Mars.—From 1700 to 1761, astronomers observed Mars with the greatest care, and obtained the best results which could be given by instruments which were reliable only to two seconds of arc. In 1719, Maraldi found the parallax of Mars to be 27″. The distance of the planet from the sun was at that time 1.37; from the earth, .37. But parallax is the angle which the radius of the earth subtends to an observer at the distant object (178): it

is, therefore, inversely in proportion to the distance of the object. Hence,

Sun's dis. : Mars' dis. : : Mars' par. : Sun's par.;
$1 : 0.37 :: 27'' : 9.99''$, nearly $10''$.

TRANSITS OF VENUS.

277. In 1725, Dr. Halley explained a method of finding solar parallax by observations of the transits of Venus, taken from remote points on the earth. The next transits of Venus occurred in 1761 and 1769. The problem to be solved was deemed so important that the governments of France, England, and Russia sent expeditions to various parts of the earth to secure observations. It was while engaged in this business that the celebrated navigator, Cook, lost his life at Hawaii. Le Gentil went to India to observe the transit of 1761, but, because of detentions on the voyage, he arrived too late. He waited the eight years for the next transit, and was then disappointed by the passage of a cloud over the sun at the critical time.

Delisle devised another method, somewhat more readily explained, from considering the transits of 1761 and 1769.

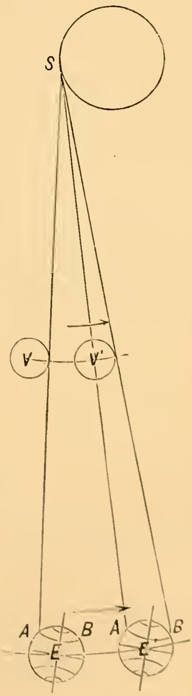


Fig. 91.

278. Delisle's method. — Suppose that two persons, each provided with a suitable telescope and an astronomical clock, are at distant places on the earth, *A* and *B*, looking for an expected transit. When Venus comes to the position *V*, the observer at *A* sees her apparently touch the sun: he notes

the time of contact. A little later, the observer at *B* marks the time at which Venus seems to touch the sun in the position *V'*. Between the two observations, the earth has moved over the arc *EE'*, which measures the angle *ASA*, and Venus has moved over the arc *VV'*, opposite a somewhat larger angle *ASB*. The value of each angle is found from the known rates at which the planets move. The difference between these two angles, the small angle *ASB*, or the amount of angular motion which Venus gained in order to make the contact visible at *B*, is the parallactic angle sought, opposite the base-line *AB*.

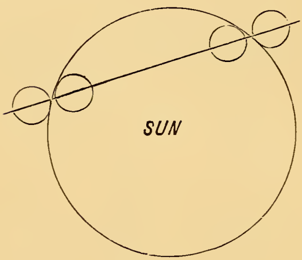


Fig. 92.

The observation is repeated by noting the time of external and internal contact on each side of the sun's disc.

279. Halley's method.—To an observer at *A*, Venus seems to cross the sun's disc on the line *ef;* to one at *B*,

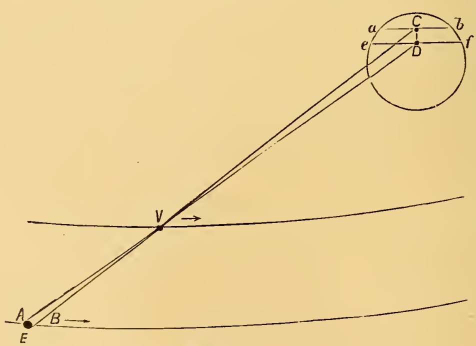


Fig. 93.

on the line *ab*. The two lines *AD* and *BC*, from the images on the sun to the observers, cross at *V*, making the

angles at V equal: the three bodies, E, V, and the sun, are in the same plane, and the lines AB and CD, perpendicular to that plane, are parallel. Hence, the triangles AVB and CVD are equiangular; but equiangular triangles have their like sides proportional; hence,

$$AB : CD :: AV : VD.$$

$AD = 1$; $VD = .723$ (273); therefore, $AV = 1 - .723 = .277$.

Hence, $AB : CD :: .277 : .723$.

Put for AB the distance in miles between the two places of observation; reduce, and we have the value of CD, the distance between the two chords ab and ef, on the sun's surface, *in miles*.

During this observation, the sun has an apparent eastward motion, at a certain rate; Venus has a westward motion, at a different rate; the sum of the two rates gives the apparent rate of the planet over the disc of the sun—so many seconds of arc in one second of time. Having noted carefully the time occupied in crossing the sun's disc, the length of the line of passage is known in seconds of arc. Construct the right-angled triangle COb, in which Cb, half the line ab, and Ob, the radius of the sun's disc, are known in seconds; by construction, or, better, by trigonometry, the triangle is solved, and CO is found. In the same way, from the triangle DOf, DO is found. DO taken from CO leaves CD, the distance between the chords, *in seconds*.

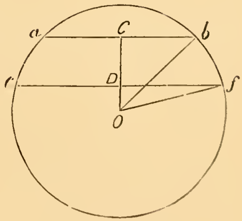


Fig. 94.

We know now how many seconds a certain number of miles will subtend at the distance of the sun.

The sun's parallax is the angle which the radius of the earth subtends at the distance of the sun (191); hence,

CD in miles : CD in seconds ::

Earth's Rad. in miles : Sun's hor. par.

280. Other methods of investigation.—The importance of the solar parallax and of the sun's distance from the earth as a unit of astronomical measurement, has caused the problem to be attacked from many directions. Professor C. A. Young enumerates thirteen methods, most of which are too abstruse to be discussed here. Among them may be mentioned calculations based upon observations of Mars when near opposition (276); of some of the nearer asteroids in similar positions; of Venus when at or near inferior conjunction, as above explained; of certain inequalities in the moon's motion; of the perturbations of the planets; of the velocity of light.

The transits of Venus in 1761 and 1769 were discussed by Encke, and the value of the parallax was placed at 8.5776″. From this the distance of the earth from the sun was computed at about 95 millions of miles (95,274,000), which was long used as the accepted value. Astronomers have found great difficulty in agreeing upon the solar parallax. Among the results obtained are the following:

281.

CALCULATIONS BASED UPON		AUTHORITY.	VALUE IN SECONDS.
Transits of Venus, 1761–69,		Encke,	8.5776
do	do	Powalky; Stone; Fay;	8.7 to 8.9
do	1874	Airy,	8.76
do	do	Tupman,	8.81
do	do	Stone,	8.88
Opposition of Mars, 1862,		Newcomb,	8.855
do	do	Gill,	8.783
Observations of the Moon,		Hansen and others,	8.83 to 8.92
Perturbations of Planets,		Leverrier,	8.86
Velocity of Light,		Cornu; Michelson	8.78 to 8.85
do		Todd,	8.808
Investigations of all known data, 1865,		Newcomb,	8.848
The British "Nautical Almanac" uses,			8.95
The Berlin "Yahrbuch" and American "Ephemeris" uses,			8.848
The French "Connaissance de Temps" uses,			8.86

Prof. C. A. Young gives, as the result of careful investigation, the value 8.8 as that having the greatest probability.

The corresponding value of the mean radius of the earth's orbit is 92,885,000, with a possible error of 225,000 miles. It is, therefore, sufficiently exact for the ordinary student to call the distance of the earth from the sun 93 millions of miles.

A difference of one hundredth of a second in parallax produces a difference of about 112,000 miles in distance.

DIAMETERS OF HEAVENLY BODIES.

282. The Sun.—We now have more exact quantities, which may be substituted for the approximations previously used (191), to determine more nearly the sun's true diameter. Insert the sun's parallax, and the sun's apparent radius, 16′ 2″, observed at the same time, and we have

$$8.8'' : 962'' : 7913 : 863{,}898,$$

the sun's diameter. More exactly 866,400.

283. Diameter of Venus.—We find the horizontal parallax and corresponding radius for the same day. For example, Jan. 1, 1883, they were, parallax 25.3″, radius, 24.4″; then,

$$253 : 244 :: 7913 : 7632, \text{ Venus's diameter.}$$

284. Diameter of Jupiter.—The parallax of Jupiter can not be measured on account of his distance.

The radius of the earth will seem to diminish as the distance at which it is seen increases. If Jupiter is four times as far from the earth as the sun, the radius of the earth will seem to an observer at Jupiter one fourth as large as to an observer at the sun. Jupiter's mean distance is 5.2028 (273); hence,

$$5.2028 : 1 :: 8.8'' : 1.69'' + = \text{Jupiter's parallax.}$$

Then, as before,

$$1.69'' : 18.26'' :: 7913 : 85400 - = \text{Jupiter's diameter.}$$

285. Size of the planets.—Spheres are to each other in volume as the cubes of their like dimensions; that is,

$$(\text{Dia. of E.})^3 : (\text{Dia. of Sun})^3 :: \text{Vol. of E.} : \text{Vol. of S.}$$
$$7913^3 : 866{,}000^3 :: 1 : 1{,}300{,}000, \text{ nearly.}$$

The average diameter of Jupiter is 10.8 times that of the earth; hence,

$$1^3 : 10.8^3 :: 1 : 1260, \text{ nearly:}$$

the volume of Jupiter is 1260 times the volume of the earth. Similarly, the diameters and volumes of other planets may be found.

MASSES OF THE HEAVENLY BODIES.

286. Definition.—The *mass* of a body is the quantity of matter which it contains. The weight of a body on the earth measures the force with which the earth attracts that body, and the attraction is in proportion to the quantity of matter, or its mass. Hence, the mass of a body is indicated by its weight.

The mass of a cubic foot of iron is greater than the mass of a cubic foot of ice, because the particles are more densely packed in the iron than in the ice. Hence, the mass is in proportion to the density, and the weight indicates the density.

287. Motion of a falling body.—Experiments prove that a body falling near the surface of the earth passes through 16.08 feet in the first second; four times that space in 2 seconds; nine times that space in 3 seconds, and so on: the distance for any number of seconds is 16.08 feet multiplied by the square of the number of seconds.

288. Downward motion of a projectile.—A projectile is any thing thrown into the air—a cupful of water, a stone, or a cannon-ball. Aim a cannon horizontally, and place it where the ball may strike a vertical wall in one

second; the ball will not follow the horizontal line of the gun, but will strike the wall 16.08 feet below that line; this has been proved by actual trial. The ball is drawn toward the

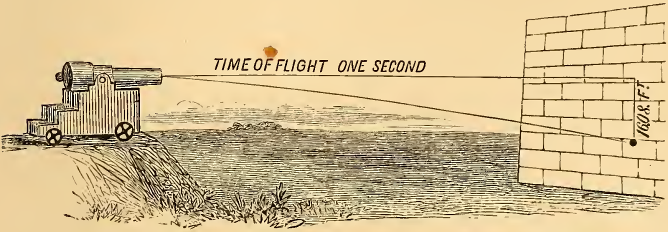


Fig. 95.

earth precisely as far as one which falls vertically from the mouth of the gun in the same time.

If the wall is so far away that the ball requires two seconds to reach it, the ball will strike 4×16.08 feet below the horizontal line.

289. The measure of gravity. — We consider 16.08 feet a measure of the attractive force of the earth, at its surface. If the mass of the earth were greater, and consequently its attractive power greater, it would draw the falling body with more force, and, consequently, make it move with greater speed.

Fig. 96.

290. The moon a projectile. — In the moon's revolution about the earth, it has a forward motion, which, with the earth's attraction, determines its path (204). Let *A* be the place of the earth, *B*, that of the moon, and suppose the moon to be driven on the line *BC* by a force which will move it to *C* in one second of time. Because of the earth's attraction, the moon will not go to *C*, but will come to the line *AD* at *D*, as if it

had fallen through the distance *CD*. *CD* is, therefore, the measure of the earth's attraction at the distance of the moon.

291. The moon obeys the law of gravitation.—Gravity varies inversely as the square of the distance (157). Hence,

$$\text{The moon's distance}^2 : \text{The earth's radius}^2 ::$$
$$\text{Gravity at earth's surface} : \text{Gravity at the moon,}$$
$$\text{or } 240{,}000^2 : 4000^2 :: 16.08 \text{ ft.} : 0.004464 \text{ ft.};$$

the distance through which the moon should fall per second in obedience to the earth's attraction.

In the triangle *ABC*, the side *AB* is known, being the distance of the moon; the angle *B* is a right angle; and the angle *A*, the angle of the moon's motion in one second: from these, we calculate the side *AC*. From *AC* take *AD*, and there remains *CD*, the distance through which the moon falls; it is 0.0044621 feet, and corresponds very closely to the preceding amount.

Closer calculation removes even this difference, and thus it appears that the space through which the moon actually falls per second is the same as that which the force of gravity would cause it to describe.

292. The earth falls toward the sun as the moon falls toward the earth. In the same figure, let *A* be the place of the sun; *B*, that of the earth; *CD*, the amount of space through which the earth falls; that is, through which the sun draws the earth in one second. As before,

$$93{,}000{,}000^2 : 4000^2 :: 16.08 : x,$$

the distance through which a body would fall in one second, at the distance of the sun, if attracted with a force equal to that of the earth. But, working the other part of the problem, as in the case of the moon, we find the actual space about 330,000 times the result found in the proportion. Hence the sun's attractive power is about 330,000 times as great as the earth's attraction would be in the same place,

and, therefore, the sun's mass must be about 330,000 times the earth's mass. Professor Young gives 330,000 ± 3000.

293. **The mass of Jupiter** is found from the motion of his satellites in the same way. First find how far one of Jupiter's satellites should fall if the sun were at its center of motion; then find how far it does fall. The ratio of the two quantities is the ratio of the sun's mass to Jupiter's mass. The method applies to any planet which has a satellite.

294. **The mass of Venus.** — The mass of a planet which has no satellite is computed from its effect in disturbing other bodies, as it comes into their vicinity. The method is too abstruse to be introduced into a work of this character.

295. **Densities.**—The density of a body is the quantity of matter contained in a unit of space, as a cubic inch, yard, or mile. It is found by dividing the whole mass by the whole volume. To compare the density of a planet, as Jupiter, with that of the earth: find what mass Jupiter would have, if of the same density as the earth, by the proportion,

Vol. of E : Vol. of J : : Mass of E : Mass of J.

If this supposed mass is equal to the actual mass (293), the densities of the two bodies are equal.

296. RECAPITULATION.

Measurements on this small globe of ours, enable us to determine:

1. The relative distances of the sun and planets.
2. The shapes of their orbits.
3. The times in which they revolve about the sun.
4. Their actual distances.
5. Their dimensions.
6. Their masses.
7. Their densities.

CHAPTER XII.

THE SUN.

297. **The sun's power.**—We recognize in the sun the center of light, heat, and attraction for all the members of the solar system. We find in him the spring of all vital action, either vegetable or animal, on our earth; the origin of most mechanical power, producing winds, tides, currents, lifting all the water which falls in rain or thunders in cataracts, and exciting electric and magnetic forces. Immense as this work done for us by the sun is, its entire action on the earth is but the 2300 millionth of the entire force generated by the sun; that part is all that our earth can intercept of the influence which radiates from the sun in all directions.

Many believe that the sun is the common origin of all the planets and satellites; that his volume once filled the immense space now surrounded by the orbit of the remotest planet; and that, as this volume contracted in size, one after another of the planets was thrown off as a nebulous ring, which afterward consolidated into a planet, and, perhaps, imitated this action in the evolution of satellites.

298. **Ideas of the sun's greatness.**—In the last chapter, we found the distance from the earth to the sun to be 93 millions of miles (281); his diameter, 866,400 miles (282); his mass, 330,000 times that of the earth (292); and his density, one fourth the earth's density.

From these abstract numbers, we obtain very indistinct ideas of absolute dimensions. We learn to estimate distance by the time required to traverse that distance: thus, we say that New York is so many hours by rail from Chicago, rather than so many miles. So we may get a notion of the sun's distance, if we estimate that an express train, running without interruption 30 miles an hour, would require more than 350 years to reach the sun, and that a telegraphic signal could not be answered in less than two hours and a half.

Were the center of the sun placed at the center of the earth, its surface would extend to nearly twice the distance of the moon's orbit.

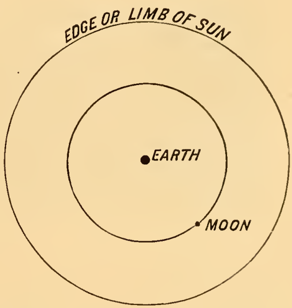


Fig. 97.

The volume of the sun is 1,300,000 times that of the earth. A French instructor, wishing to illustrate the relative volumes of the earth and sun, laid down a single grain of wheat to represent the earth. He then estimated the quantity which 1,300,000 grains of wheat would make, and poured the wheat in a pile, to represent the bulk of the sun; it required about 4 bushels.

The mass of the sun might be expressed in tons, but the long array of figures would give no definite or valuable idea. It is about 330,000 times that of the earth, and about 750 times that of all the known bodies which revolve about him.

299. The sun from other planets.—The intensity of solar light, heat, and attraction varies inversely as the square of the distance (157). The apparent breadth of the sun varies inversely as the distance (182). The figure shows the relative size of the sun as viewed from the various planets.

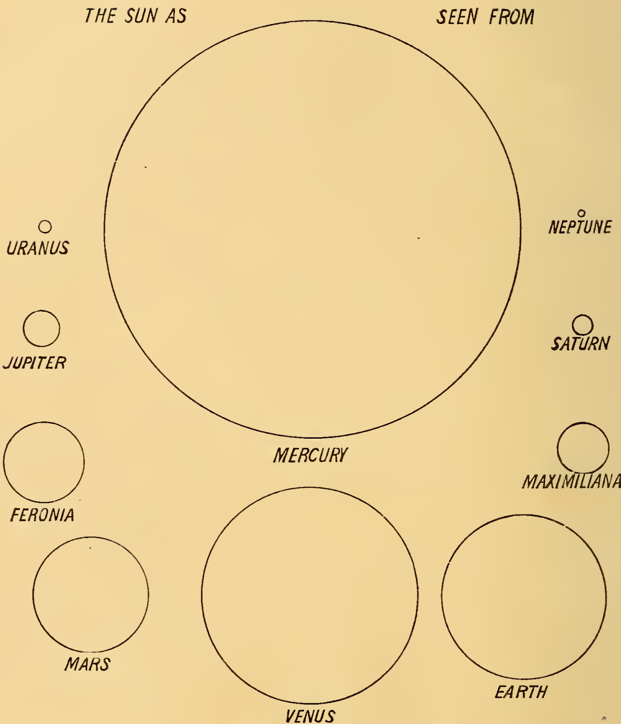


Fig. 98.

THE PHYSICAL NATURE OF THE SUN.

300. Solar spots.—When viewed through a piece of smoked or colored glass, to protect the eye from the intense light and heat, the sun shows a round disc, of a uniform golden hue; in a telescope of moderate power, its surface is often seen to be marked by irregularly placed dark spots. Observations of the same spots, continued from day to day, show that they appear at the eastern limb, cross the disc in about fourteen days, and vanish at the western edge; they

often re-appear in about four weeks from the time when first seen. At first the spot shows merely a dark line, parallel with the edge of the sun; as it advances, it grows broader, and after it has passed half way across the disc, it diminishes again to a line. The motion seems more rapid near the center of the disc than near the margin. From the varied

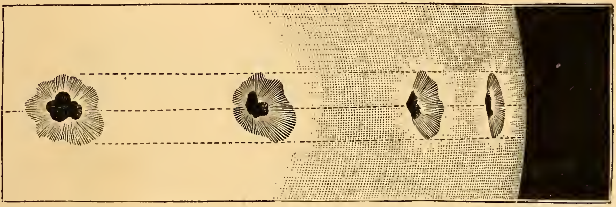


Fig. 99.

figure and rate of motion of the spots, it appears that the sun is spherical, while the fact of their movement indicates a rotation of the sun on its axis. A dark spot painted on a globe presents similar appearances, if the globe is made to rotate.

301. **Time of the sun's rotation.** — The spots seem to complete a revolution in 27.5 days, but some of this time must be due to the motion of the earth; the spot and the earth perform a synodic revolution (265) in that time. If the sun were to rotate only as fast as the earth revolves about it, the spots would appear stationary; hence, the motion of the earth apparently cancels one rotation of the sun in each year. The sun seems to make $365.25 \div 27.5 = 13.28$ rotations in a year, and really makes 14.28 rotations in that time, or one in 25.38 days.

302. **Position of the solar axis.** — In June and December, the spots appear to cross the disc in straight lines; in spring, the lines curve toward the northern margin; in autumn, toward the southern margin. From this, it appears

that the axis of the sun is inclined to the plane of the earth's orbit, and that the spots describe parallels of solar latitude

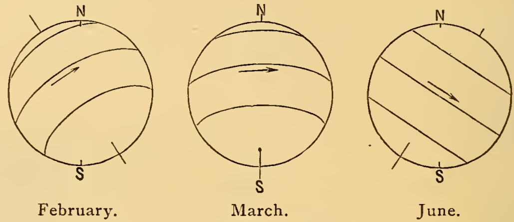


Fig. 100.

which seem to curve from the pole which is nearest the earth. The inclination of the axis is 7° 15′.

The spots appear only in a belt, called the *royal zone*, extending about 35° on either side of the solar equator.

Besides the general movement from the eastern to the western margin of the sun, as seen from the earth, the spots

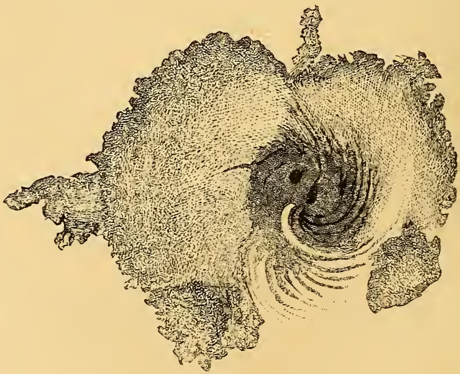


Fig. 101.—Solar Cyclone.

have irregular motions of their own, so that a spot may seem to be hurried, or delayed, to diverge to right or left; sometimes they show a whirling motion.

303. **The appearance of a spot.**—It consists usually of a dark part, called an *umbra*, surrounded by a gray, furrowed border, called a *penumbra*. The edges of both portions are ragged and irregular; several *umbræ* are often inclosed in a single penumbra, the gray portion seeming to make bridges across the dark. Often there are penumbræ

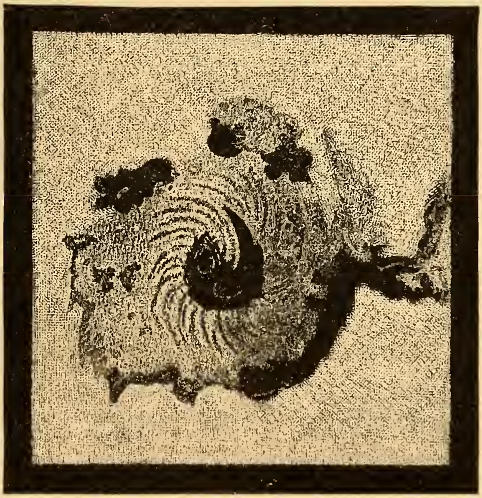


Fig. 102.

with no dark center, and umbræ with no gray margin. The penumbra is darkest near its outer edge, and brightest near the dark portion. In the umbra, a still darker part, called the *nucleus*, has lately been observed. It is possible that none of the shades are really black, but only seem so by contrast with the brilliant disc of the sun, since the most intense artificial light shows black against the sun's disc. Transits of Mercury prove that the umbra is not so dark as the unilluminated side of a planet.

304. Dimensions and variability.—Many have been visible without a telescope. Diameters are recorded of 29,000, 50,000, and 74,000 miles; in 1839, a spot appeared, whose penumbra was 186,000 miles long. The largest recorded spot was seen in 1858; it covered one thirty-sixth of the sun's surface, and had a breadth of 143,000

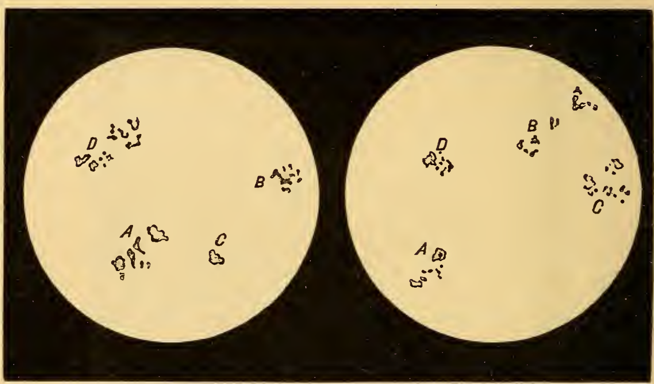


Fig. 103.—Changes in sun-spots during one rotation of the sun, observed on the 24th May and 21st June, 1828. (Pastorff.)

miles. Were these spots cavities in the substance of the sun, our earth would lie in one of them like a bowlder in the crater of a volcano. In form and size, the spots vary rapidly and constantly. It is often difficult to recognize them as they re-appear, and even under the eye of the observer they change materially. When a new spot appears, the umbra is first seen, then the penumbra, afterward the nucleus within the umbra; the whole often attains its full size in a single day, and may vanish as soon, or remain for weeks, or even months. When the spot vanishes, the sides contract to a point, the penumbra closing last. While the spot is increasing, the edges are sharp and well defined; as it vanishes, they seem to be covered with a mist or vail.

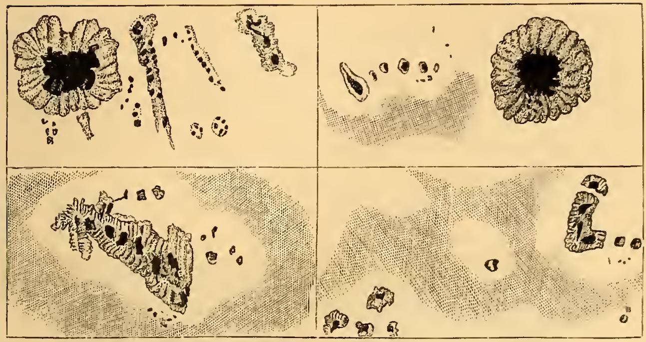


Fig. 104.—Details of groups *A* and *B*, in last figure.

305. Periodicity.—The number and size of the spots vary greatly in different years. Wolf has examined the records from 1610, and has found the successive periods of greatest and least abundance. The times between successive periods of greatest numbers vary from seven to sixteen years, but have an average of about 11⅛ years. The last maximum was probably in 1882. An attempt has been made to connect this recurrence of sun-spot years with the conjunctions or oppositions of some of the planets, particularly Mercury, Venus, and Jupiter, but the periods do not correspond with sufficient closeness, and it would be difficult to understand how the planets could cause such results.

Certain magnetic disturbances on the earth are found to occur most frequently when the sun-spots are most abundant. The *aurora borealis* is most frequently seen at the same periods. Cyclones at sea and tornadoes on land have been observed to be numerous and destructive in sun-spot years, notably in 1882. If these phenomena have a mutual dependence, as seems likely, it has not yet been discovered.

306. Faculæ.—Curved and branching streaks more brilliant than the rest of the sun, quite distinct in outline and separating into ridges and net-work, are often seen near large

spots, or where spots have vanished, or where they afterward appear. They are called *faculæ*, little torches. They are of all magnitudes, from barely discernible narrow tracts 1000 miles long, to complicated and heaped-up ridges 40,000 miles long by 1000 to 4000 miles wide.

Mr. Dawes has proved that these are mountainous billows of luminous matter raised above the general surface. In

Fig. 105.—Mottled surface of sun.—Secchi.

1859, he observed a ridge near the edge of the sun, projecting like a range of hills, whose height could not be less than 500 miles.

307. **The general surface** of the sun has a mottled appearance, easily observed, even with small telescopes. (Fig. 105). In a large instrument, the surface seems composed of patches of light, separated by rows of minute, dark spots, called *pores*. The luminous masses have been compared in shape to "willow-leaves," "rice-grains," "granules," "things twice or thrice as long as broad," etc. They may be distinct masses of luminous matter, or simply waves,

ridges in the grand ocean of flame, continually changing in outline and position, like waves in the sea. They are not seen on the faculæ, but similar forms surround the margins of penumbræ, stretching out toward the interior of the spot.

308. **Depression of the spots.** — That the spots are hollows in the general surface of the sun is shown by the appearance of the penumbra as it moves over the sun's disc. Dr. Wilson observed, in 1769, that while the spot is near the eastern margin, the penumbra is wanting on the side nearest the center of the sun's disc; as the spot moves on, the penumbra shows about equal breadth on either side; and as the spot approaches the opposite limb, the breadth of the penumbra is greatest on the farther side. These variations are clearly shown in Fig. 98.

THE POLARISCOPE.

309. When the light passes through certain substances, as a thin slice of tourmaline, or of Iceland spar, properly arranged, a peculiar effect is produced, called *polarization*. A description and explanation of these effects, and of the various substances which produce them, belong to the science of optics. It is enough for our purpose to know that these effects, though various, are uniform in light which comes from the same kind of source. The instrument used is called a *polariscope*. By it the observer can distinguish between emitted and reflected light, and between the light furnished by a glowing *solid*, as platinum; a *liquid*, as melted iron or glass; or a *gas*, as the flame produced by the burning of a candle, of illuminating gas, etc.

Arago determined that the light of the sun is such as is emitted from a burning gas, a flame. This analysis indicates that the visible surface of the sun, called the photosphere, is composed of gaseous matter in intense combustion. That it is not a solid is shown by the very rapid changes seen in the

spots and faculæ. The faculæ and willow-leaved "things" are but the billows in this grand ocean of flame; they are masses which appear brighter on account of the greater intensity of the flame, or on account of the position in which they lie in respect to us, since the edge of a flame is brighter than its side. Henry and Secchi have each shown that the dark spots emit less heat than the luminous surface.

SPECTRUM ANALYSIS.

310. **The solar spectrum.**—A ray of sunlight admitted into a dark room shows a round, white spot upon a screen which receives it. If a prism be placed in its path, the white spot is refracted to a different place on the screen, and is extended into a long band, called the *solar spectrum*, which shows all the colors of the rainbow. In 1802, Wollaston discovered dark lines, which cross the spectrum in various places. They were afterward called *Fraunhofer's lines*, from a German optician who named those most easily observed, and carefully mapped their places. From 600 to 2000 are seen with spectroscopes of various powers.

311. **Spectrum analysis.**—When we analyze light from a flame which contains some metallic vapor in combustion, certain colored lines are produced, which are peculiar to the substance burned. Thus, sodium shows its presence by two very fine, bright yellow lines placed close together, all the rest of the field being perfectly dark. The sign of potassium is a bright red line near one end of the spectrum and a bright violet line near the other end. In 1815, Fraunhofer observed that the yellow lines coincide in position with two dark lines in the solar spectrum; in 1842, Brewster noticed a similar fact in regard to the potassium lines.

312. **Laws of spectrum analysis.**—Kirchhoff found that when the rays of a flame colored with sodium, for

example, pass through vapor of sodium, the bright lines in the spectrum vanish, and black lines appear in their places.

By these and similar experiments these laws of spectrum analysis have been determined.

1. When *solid* or *liquid* bodies emit light, their spectra are *continuous*, unbroken either by dark or bright lines.

2. Every element or compound that emits light when in a *gaseous* condition, is distinguished in the spectrum by *bright colored lines* peculiar to itself.

3. *Vapors of metals* or *gases* neutralize or absorb the colored rays which they would themselves emit.

313. **The nature of sunlight.**—Let a prism be so arranged that a beam of sunlight is decomposed by one portion, while a beam from burning gas, containing vapor of some substance, as iron, zinc, or sodium, is decomposed by another portion, the two spectra being placed side by side. The bright lines of the metals are found to coincide precisely with dark lines in the solar spectrum, and, by proper arrangements of apparatus, the dark lines may be transformed into bright lines at the will of the experimenter. Hence, we conclude that the dark lines in the solar spectrum which correspond to iron, for example, are caused by iron burning in the sun, the light from which passes through other vapor of iron in the sun's photosphere, and has there had its peculiar spectral powers absorbed.

This analysis gives evidence of the presence in the sun of twenty-two elements, among which may be named oxygen, hydrogen, calcium, sodium, magnesium, chromium, barium, nickel, cobalt, iron, copper, manganese, and lead.

PHENOMENA OF SOLAR ECLIPSES.

314. Much of our knowledge of the envelope or atmosphere of the sun which lies above the photosphere (309) has been obtained when the direct light of the sun has been

obscured in a total eclipse. (Fig. 106). The most notable phenomena then observed are the *corona*, with its *luminous streamers*, and the *red prominences*.

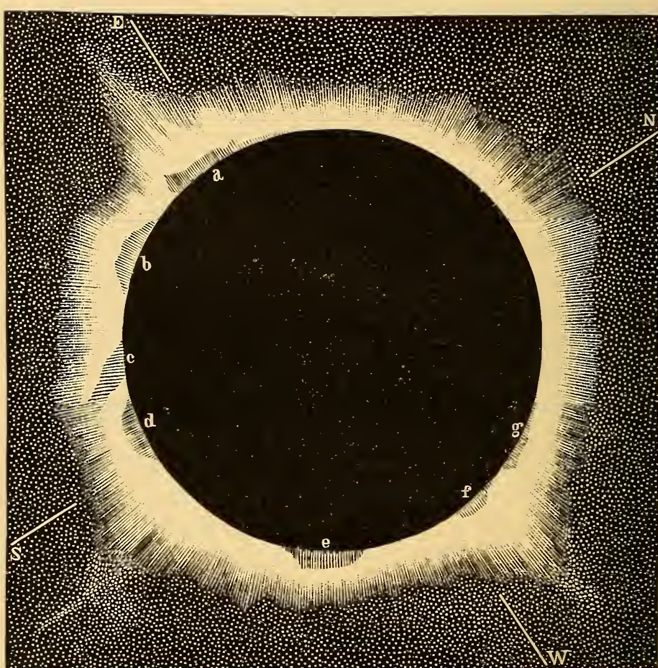


Fig. 106.—Eclipse of August, 1869.

315. **The corona.**—When an eclipse of the sun becomes total, as the last gleam of direct sunshine vanishes, a beautiful vision appears in the darkened sky. The black disc of the moon is surrounded by an effulgence of radiant, pearly light, that is feebly represented by the halo which painters draw about the heads of saints. Near the moon, the tint is rosy; thence emanate an infinity of rays of white and yellow and violet light. This glory is called the *corona*.

Its duration at any eclipse is rarely so long as five minutes, and these minutes astronomers deem very precious.

The ring of light about the sun has a breadth rather uniformly three or four minutes of arc. (Fig. 107). Beyond this ring irregular rays or streamers reach a much greater distance, sometimes traceable as far as six or seven degrees of arc.

It will be remembered that a minute of arc means at the sun a distance of nearly 28000 miles; a degree of arc means

Fig. 107.—Eclipse of July, 1860.

more than 1600000 miles, or nearly twice the sun's diameter. A series of drawings of solar eclipses shows remarkable variations in the position, form, and extent of these luminous radiations.

316. Where is the corona?—It has been by some accounted for as merely an effect of the sunlight in the atmosphere of the earth, or of the moon. But the radiance centers not in the moon, but in the sun, and the moon passes by the corona, instead of carrying it forward with itself. Young believes that observations made by himself, and

independently by Harkness, in 1869, settle conclusively that the corona is a manifestation of the sun's atmosphere. Each saw in the spectroscope (310) a bright green line—the famous 1474 line, so called from its place in the Kirchhoff scale—which proves the presence of a burning gas in the corona, and, therefore demonstrates its connection with the sun.

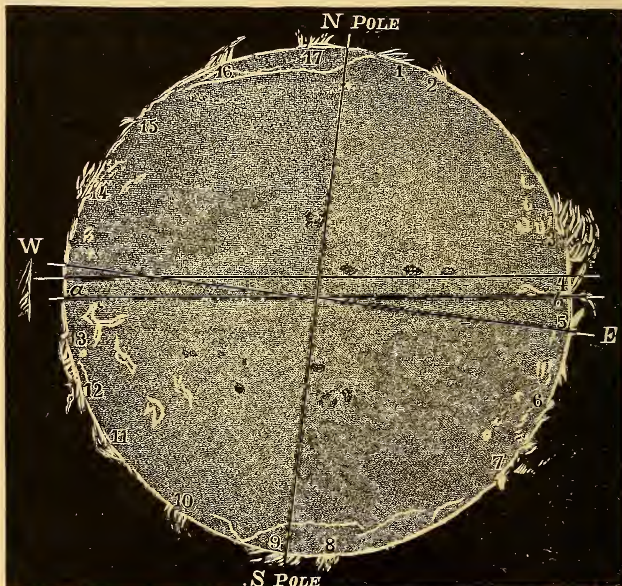


Fig. 108.—The sun, with protuberances and red flames, July 23, 1871. After Secchi. The figures mark the flames, 17 in number.

317. **What is the corona?**—The lower part is the sun's atmosphere, made luminous by heat and by reflection. The cause of the streaming rays has not yet been found.

318. **The red prominences** are also seen at the time of totality in a solar eclipse. (Fig. 108). They are flame-like emanations in the lower regions of the corona, as varied in

form, and often as fantastic, as the clouds in our summer skies. The larger ones may be seen without any magnifying power extending 3′ from the sun.

Previous to the solar eclipse of 1868, special preparations had been made for studying the lines of the red prominences with the spectroscope, while the sun was obscured, and the results were successful. Then the discovery was made, by Janssen and by Lockyer, independently, that these phenomena could be seen by directing the instrument to the edge of the sun's disc at any time, and without waiting for an eclipse. Since then, Huggins, Zöllner, Respighi, Young, and others have made careful studies of these most interesting forms.

319. **What are they?**—Young describes them as *quiescent*, or hydrogenious, and *eruptive*, or metallic. The quiescent forms, in their resemblances and differences, are like the clouds in our own atmosphere. Great masses lie without change for hours, and even during a whole solar rotation. They are often connected to the sun's surface by falling fringes, which suggest summer showers. Secchi has seen these cloudlets form and grow as clouds form at the earth. Their spectra indicate the presence of hydrogen with sodium and magnesium.

The eruptive prominences are brilliant jets thrown up from the sun's surface, often with tremendous energy. Their spectra show the presence of numerous metals in great abundance. These prominences are frequent near sun-spots, and are particularly abundant near faculæ.

320. **Their magnitudes.**—Their altitudes are usually not more than 20,000 miles. A few reach up to 80,000 or 100,000 miles high. Secchi saw one of 300,000 miles, and Young, in 1880, saw one reach the enormous elevation of 350,000 miles. The movement of this eruptive discharge may illustrate the intense energies which are acting at the sun. When first seen, at 10.30 A. M., this prominence was about 40,000 miles high, and attracted no special attention;

in thirty minutes it had doubled its height; in another hour it had reached the great altitude stated; by 12.30, two hours from the time when it was first observed, it had utterly faded away. While rising, a rapid rotary motion was seen in its lower portions.

SOLAR LIGHT AND HEAT.

321. **The intensity** in heating, lighting, and chemical power of the sunlight which comes from the margin of the disc, is found to be less than that from the central portions. If the energy at the center were called 100, that at the margin is as follows:

Heat rays (Langley),	50, or ½.
Light rays (Pickering),	37, or ⅜.
Chemical rays (Vogel),	13, or ⅛.

This variation will be fully explained if we suppose that the sun is surrounded by an atmosphere. The rays which come to us from the center of the disc have a relatively short path through the solar atmosphere; those from the margin a longer path, and a larger part of the energy is absorbed. Under such conditions chemical rays are known to be most readily absorbed, and heat rays least readily.

Experimenters differ widely in their estimates of the intensity of sunlight at the sun's surface. Foucault and Fizeau found it 146 times brighter than the lime-light. Langley found it 5300 times brighter than the molten steel in a Bessemer converter. The intensest light from the electric arc has been estimated at one fourth and even at one half that of sunlight. Yet either the lime-light or the electric arc shows as a black spot when viewed against the sun's disc.

The total quantity of sunlight, stated in candle power, of sperm candles, weighing six to the pound, and consuming 120 grains per hour, is 63×10^{25} (Young).

322. **Solar heat.** — John Herschel found that the heat received at the earth, the sun being in the zenith, would melt ice one inch thick in two hours and thirteen minutes. Remembering that the intensity of heat varies inversely as the square of the distance, and also the limited portion which the earth can receive, he obtained a result which he expressed by saying that if the total heat emitted by the sun could be concentrated upon the end of a pillar of ice 45 miles square, the ice would be melted, even if flowing into the sun with the velocity of light. As Young puts the illustration, if a column of ice two and one fourth miles in diameter could span the 93 millions of miles between the earth and the sun, the sun's heat would melt the whole in one second, and change all to vapor in seven seconds more.

The difficulty of estimating the rate of radiation at high temperatures has led to great differences of opinion concerning the temperature at the sun, as follows:

Secchi,	18,000,000°;	later,	250,000° F.;
Ericsson,	4,000,000°	to	5,000,000° F.;
Zöllner and others,	50,000°	to	100,000° F.;
Pouillet and others,	3,000°	to	10,000° F.;
Rosetti, approved by Young,			18,000° F.
The intensest artificial heat is about			4,000° F.

THEORIES CONCERNING THE SUN.

323. **Of structure.**—The facts learned about the sun since the discovery and use of the spectroscope have added much to our knowledge of solar physics, and have wholly changed the theories of the sun's structure. Astronomers are now substantially agreed upon these points:

1. The mass of the sun is composed of matter, much of which is recognized as identical with elements found in the earth; other materials are not yet determined.

2. The interior mass of the sun is in a gaseous condition at a very high temperature of unknown degree, but too high to be luminous.

3. The central gaseous mass is surrounded by a stratum several thousand miles thick, cooled to a consistency sufficiently great to hold in check for a while the central eruptive forces, but occasionally compelled to yield to them and to allow the discharges seen as eruptive prominences; this stratum, though cooler than the mass within, is still heated intensely, and to the degree that makes it brilliantly luminous. It is called, for this reason, the photosphere.

4. The outer part of the photosphere grades into matter of less density, forming a gaseous layer in which float many-hued masses of incandescent substances. This stratum is called the chromosphere, and has been described as a "sheet of scarlet fire."

5. Above the chromosphere, and also separated by insensible gradations, lies an atmosphere of transparent gases of constantly decreasing density. This stratum has a great but unknown thickness, and is most clearly seen as the corona, at times of solar eclipse.

324. **Of the spots and faculæ.**—The mass of matter in the sun constantly loses heat from its outer portions by radiation into space, and that the more rapidly because its temperature is so high. The cooler matter of the outer portions falls in currents towards the center, as rain falls on the earth, while the heated interior matter rises in counter currents. The alternating currents may be everywhere intermingled, as if the seething mass were full of rising bubbles and descending currents, producing the usual appearance at the surface of pores and billows (307); or the separate movements may be massed together in terrific storms, sometimes whirling over large areas, sun-cyclones, the rotary movement of which is often visible from the earth. The tops of the ascending columns are the faculæ (306). The descending

currents carry the matter of the photosphere into the hotter interior of the sun, and form depressed cavities, in which all the visible material melts away in the intenser heat, giving a temporary view of the non-luminous interior. The sun-spot is a vortex or maelstrom into which the neighboring matter pours, the motion being compensated elsewhere by counter upward currents.

325. **Of the red prominences.**—These are either cloud-like masses of hydrogeneous matter, blown out from the interior, and upheld above the chromosphere because of their vaporous lightness, or of metallic matter, ejected in streams through openings in the denser layer of the photosphere, that for a time holds the matter below in check, but yields at length to accumulating and explosive forces. This matter may ascend to great heights, but soon falls back upon the surface of the photosphere.

326. **Of the causes of solar heat.**—There are three principal theories:

1. *That of combustion;* the chemical combinations of matter, illustrated on the earth by the union of carbon and oxygen in our fires. To this theory objection is made that we know of no adequate supply of fuel. Were the sun solid carbon, and were oxygen supplied as fast as needed, the whole would burn out in 6000 years. Were the fuel something of a more enduring nature, still the prodigal consumption would exhaust the whole in a time which would be brief when compared with the periods of natures changes.

2. *The meteoric theory.*—That the heat is produced by the continued fall of meteoric bodies upon the sun's surface. It is now a settled principle of physics that heat and motion are but different phases of the same force; that one may be changed to the other, and that in no way can either be destroyed. The sudden arrest of a moving body, as of a meteor falling to the earth or the sun, develops instantly an amount of heat which is the mechanical equivalent of the

motion stopped. Doubtless some heat is so produced, but what can be the source of the meteoric stream which, plunging into this insatiable abyss, could alone maintain such a lavish expenditure of solar energy? If the heavenly spaces are furnished with sufficient store of meteoric bodies to keep the sun in action, should not the earth receive a quota from the same supply, enough to maintain a large degree of heat in it also?

3. *The contraction theory.*—That the heat is caused by the contraction of the sun's material and its gradual change from gaseous to liquid and solid conditions. Each of these processes must be accompanied by the liberation of vast amounts of heat. Helmholtz has estimated that a contraction of the sun's radius of 125 feet per year—equal to a mile of diameter in 21 years—would account for all the present heat-emission. One second of arc equals 450 miles, at the distance of the sun from the earth; to reduce the sun's apparent diameter one second, which is as little as could be detected, would require 450 × 21 years, or nearly 10000 years.

327. RECAPITULATION.

The sun is the center of forces for the solar system.

Spots appear upon its surface. They are *cavities* of great and very variable dimensions; *rotate* from west to east; show several *shades of color;* are accompanied by *brighter* spots, called *faculæ.*

The *polariscope* shows that the photosphere consists of *gaseous matter* at a *white heat.*

The *spectroscope* shows the presence of *hydrogen*, *sodium*, *iron*, and other terrestrial substances.

During *solar eclipses* a solar atmosphere or *corona* is visible; the *red prominences* may be seen at the same time, and at other times by means of the *spectroscope.* The prominences are *hydrogeneous* or *metallic.*

Theories concerning the sun.

The sun contains some *elements found in the earth.*

The interior is *gaseous*, *intensely heated;* surrounded by

1. The *photosphere*, self-luminous, of glowing flame;
2. The *chromosphere*, of lighter, colored flame;
3. The *atmosphere*, of transparent gases.

The *spots* are openings through the outer strata into the gaseous mass below, caused by descending currents. The *faculæ* are caused by ascending currents.

The *red prominences* are matter ejected from the interior.

The causes of solar heat are one or all of these:

1. *Combustion.* 2. *Meteoric* bodies which fall into the sun. 3. *Contraction* and *condensation* of *gaseous* matter into *denser forms.*

CHAPTER XIII.

THE MOON.—SYMBOL, ☽.

328. Positions as related to the earth and sun.—We have learned elsewhere (177–184) that the moon is a globe about 2,000 miles in diameter, and that it revolves about the earth in an elliptical orbit, at an average distance of about 240,000 miles.

When the sun and moon have the same celestial longitude, they are in *conjunction* (261). They rise, come to the meridian, and set at about the same time. When their longitudes differ by 180°, they are in *opposition;* one rises as the other sets. The places of opposition and conjunction, when spoken of together, are called the *syzygies.* When the moon is midway in the sky between opposition and conjunction, 90° from either, it is in *quadrature.* The four points between the syzygies and quadratures are called *octants.*

329. Lunar periods.—The time occupied by the moon in passing through all the aspects from conjunction to conjunction again is called a *lunation.* It is the same as a *synodic revolution* (265). Its mean length is 29 d. 12¾ h. (29 d. 12 h. 44 m. 3 sec.).

The time of a mean sidereal revolution is 27 d. 7¾ h. (27 d. 7 h. 43 m. 11.4 sec.).

330. The synodic revolutions not equally long.—When a body moves in an elliptical orbit, its rate of motion is so varied that its radius vector describes equal areas in

equal times (201); hence, the body moves fastest when nearest the focus. If, then, the space 2-3, which the moon has to traverse in order to overtake the sun after finishing its sidereal revolution, is near apogee, where the moon moves slowly, more time will be taken, and the lunation will be long; if the space be near perigee, the moon moves rapidly, and the lunation will be short. Moreover, the motion of the earth in its orbit is not uniform, and the arc *AB* varies in length, which will also cause variation in the lunation; these two causes may partially counteract, or may assist, each other.

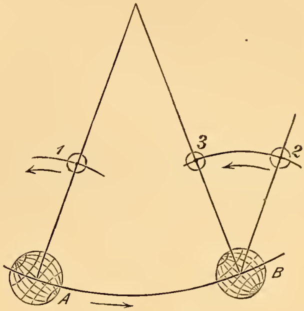


Fig. 109.

331. The moon moves about the sun as well as about the earth.—The moon obeys the attractions of both the earth and the sun. Were the earth instantly blotted from existence, the moon would continue to move about the sun in an orbit resulting from the forward motion of the moon, modified by the sun's attraction.

332. The moon's path is always curved toward the sun.—Let *AB* represent part of the earth's orbit, and let 1, 2, 3, etc., represent successive positions of the earth

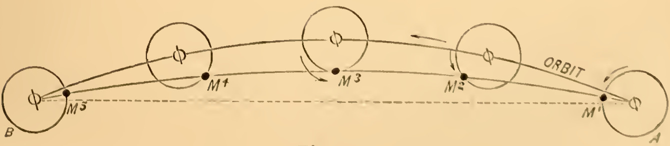


Fig. 110.

and moon, the small circles showing the moon's orbit. It is evident that while the moon revolves about the earth, even

in the part of its motion which is nearest the sun, it is always beyond the straight line which connects *A* and *B*, and follows a line which is always curved toward the sun. Its deviations from the earth's path amount to only about $\frac{1}{388}$ part of the radius of the earth's orbit.

THE SUN'S ATTRACTION.

333. **Its effect on the eccentricity of the moon's orbit.**—Were the moon influenced by no other attraction

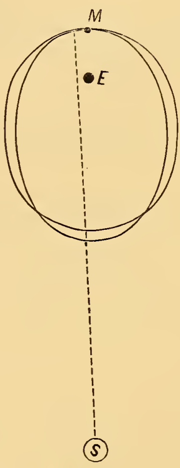


Fig. 111.

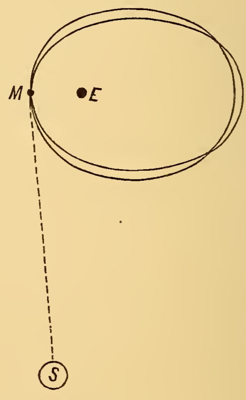


Fig. 112.

than that of the earth, the line of apsides would point always to some fixed point in the heavens, as the earth's axis is directed to the pole star. Now suppose the moon's orbit in such a position that the line of apsides is directed toward the sun. As the moon passes opposition, the force of the sun is added to that of the earth, drawing the moon more forcibly toward the center, and increasing its speed. As the moon approaches conjunction, the force of

the sun diminishes that of the earth, and the moon does not turn about as soon as it otherwise would. The action in either case makes the moon's orbit narrower and longer—more eccentric.

334. **Conversely.**—A few months later, the line of apsides coincides with the quadratures; the attraction of the sun no longer assists the radial force, but acts at right angles to that of the earth; the moon as it passes apogee or perigee, begins to turn sooner, and makes its path more nearly circular—the eccentricity is diminished. (Fig. 112.) Hence, it appears that the moon's orbit is one of variable eccentricity, and that the cause is continually correcting itself.

335. **On the position of the line of apsides.**—In some positions, one of which is illustrated in the diagram, the attraction of the sun being at right angles to that of the earth, the earth can not pull the moon into place, causing it to turn about, quite as soon as it should; and the place of perigee, instead of being at M^1, as at the last passage, goes on to M^2; a new line of apsides is thus fixed, a little turned from its former place. Under other circumstances, the opposite effect is produced, but the forward are greater than the backward movements. The line of apsides makes a complete revolution in about nine years.

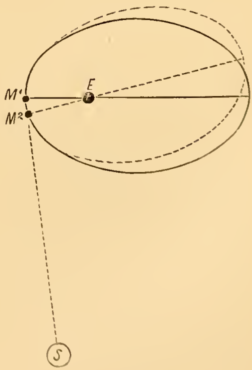


Fig. 113.

336. **On the position of the line of nodes.—Definitions.**—Daily observations of the moon's right ascension and declination, traced upon a celestial globe (108), show the moon's path is alternately north and south of the ecliptic, departing as much as 5 degrees (5° 9′). Hence, it appears that the plane of the moon's orbit is inclined to that of the

earth by such an amount. The points where the moon's orbit passes through the plane of the ecliptic are called its *nodes;* that where the moon goes from south to north is the *ascending node;* the opposite, the *descending node.* The line which joins these points, passing, of course, through the earth, is the *line of nodes.*

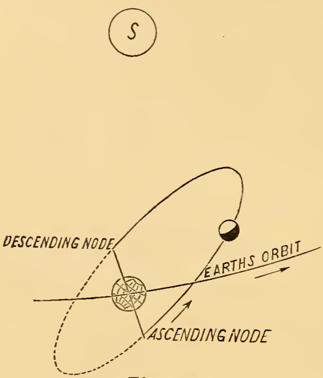


Fig. 114.

337. **The nodes move backward.** — Whenever the moon is out of the plane of the ecliptic, the sun tends to draw it back into that plane. As the moon approaches the node nearest the sun on the line *AN*, the sun does not allow it to pass on to *N*, but draws it in to the ecliptic a little sooner at N^1, and causes it to cross at a somewhat greater angle. Immediately after the passage, as the moon is moving away on the new line, the attraction of the sun still draws it back toward the ecliptic, and restores the path to the same angle that it had before, bringing the moon into the line N^2B, parallel to the first line *AN*. The result of the whole action is to move the node from *N* back to N^2, while the obliquity of the orbit is left unchanged. The moon's path is represented by the slightly curved dotted line. At the node farthest from the sun this effect is reversed; but because the sun is farther from the moon by the diameter of the moon's orbit, the effect is not so great as at the nearest node.

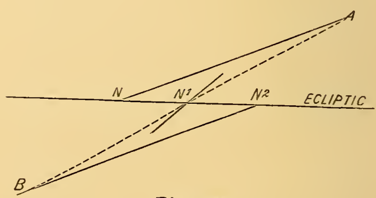


Fig. 115.

Hence, the line of nodes moves slowly backward, and completes a revolution in about 19 years (18.6 y.).

338. **Results.**—The moon's motion is, therefore, a combination of these several elements:

1. Its revolution about the earth.
2. Its revolution about the sun.
3. The vibrating eccentricity of its orbit.
4. The slow direct rotation of the line of apsides.
5. The slow retrograde rotation of the line of nodes.

Besides these, there are minor perturbations caused by the attraction of the planets at varying distances.

339. **Illustration.**—An idea of these several motions may be rudely realized thus:

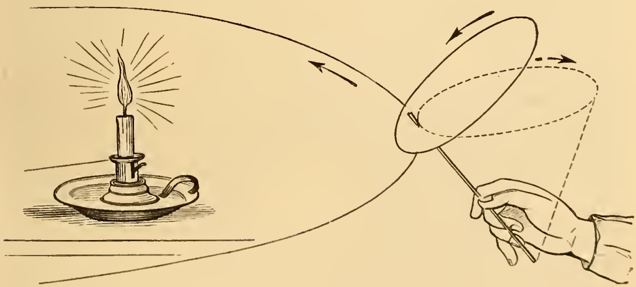


Fig. 116.

Cut an ellipse from stiff paper or card-board; thrust a pencil through one of the foci, in the place of the earth; conceive the moon to move round the edge of the card, and that the card itself slightly expands in length and contracts in breadth, and *vice versa*. Hold the pencil obliquely, that the position of the card may represent the obliquity of the orbit. Turn the pencil in the fingers, slowly, *opposite* to the motion of the hands of a watch, and we have the motion of the apsides. Hold the lower end of the pencil stationary, and make the upper end describe a circle slowly, in the *same* direction as

the hands of a watch, always preserving the same angle of inclination, and we have the motion of the line of nodes. Make all these motions together while walking about some fixed point to represent the sun; we find that the motion of the moon, though intricate, may be followed and comprehended.

PHASES.

340. The phases of the moon.—The new moon in the west shows a narrow crescent, its convex side toward the

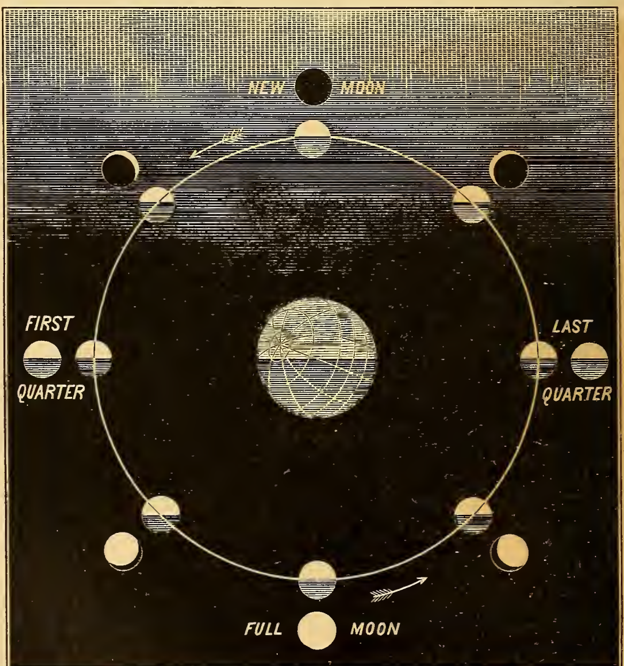


Fig. 117.

sun. As the moon grows older the crescent widens, and when it rises in the east as the sun sets in the west, its face

is full and round. It then diminishes as it had increased, showing at last a narrow crescent in the east, shortly before sunrise, the convex side still being toward the sun. Between the time of old and new moon it sometimes passes between us and the sun, obscuring the sun's light with a broad black disc. These changes are readily understood, when we consider that the moon is an opaque body, which is bright only as it reflects sunshine. When the moon is in conjunction, the side on which the sun shines is turned from the earth, and the moon can not be seen unless it comes exactly between the observer and the sun. At the first octant, the half which is visible at the earth includes a part of the half which is lighted by the sun, and we see a crescent. At the first quarter, half of the visible side includes half of the illuminated side. At the full moon, the whole illuminated side is turned toward the earth.

341. **The ashy light of the moon.**—On the first or second clear night after new moon the entire disc may be seen; a thin bright crescent is on the side nearest the sun, while the rest of the disc shows a pale, ashy light, barely discernible. The earth is an opaque body, lighted by the sun, and, therefore, presents to the moon a series of phases, similar to those which we see in the moon, but in a reverse order. When we see new moon, an observer at the moon would see "full earth;" but as the diameter of the earth is nearly four times that of the moon, it gives nearly sixteen times as much light to the moon as the moon gives us. This light, the light of the sun reflected by the earth, is again reflected by the moon, and causes the ashy light over the otherwise invisible part of the disc. As the moon grows older, the ashy light vanishes in contrast with the more brilliant light of the part illumined by the sun.

"Late yestre'en I saw the new Moon,
With the old Moon in her arms."

IN THE TELESCOPE.

342. **In a telescope** of moderate power the moon ceases to show a flat disc, but rounds into a beautiful sphere, which seems to float in the air. Its surface is roughly irregular. Especially about the first quarter, the *terminator*, or the line which divides the light from the dark part of the disc, is very much broken. Bright spots appear a little beyond the line; in a few hours they unite with the light portion, and are then followed by dark shadows stretching away far from the sunshine. At full moon, these strong contrasts vanish, but there is yet a great variety of light and shade.

343. **Lunar mountains.**—The bright spots are the tops of lunar mountains, gilded by the rising sun. As the slow rotation of the moon brings the mountains farther into sunshine, the light is seen gradually creeping down their sides, and joining that in the valleys below, while the shadows are thrown in the opposite direction. These shadows disappear under the vertical sun at full moon, and are cast on the opposite side of the mountains as the moon wanes. The height of the mountains may be estimated from the length of the shadows, or from the distance from the terminator at which the bright top may be seen (16). The highest have an elevation of about 25,000 feet, but little less than that of the highest mountains on the earth.

344. **Lunar maps.** — Much labor has been expended upon maps of the moon's surface, the most accurate, as yet, being that of Messrs. Beer and Mädler, 30 inches in diameter. The "Moon Committee" of the British Association have parceled the moon out, and are preparing a map 100 inches in diameter, with all the accuracy of photography. The various mountain ranges have been named for ranges on the earth; single peaks and craters for eminent astronomers; level portions, under an old supposition, were called

seas and marshes, as Sea of Tranquility, Sea of Nectar, Ocean of Tempests,—names entirely fanciful.

345. **Lunar craters.**—A peculiar feature of the lunar landscape is the great number of rings, walled basins, or craters. These appear to be of volcanic origin, if not the

Fig. 118.—Mountains of the moon; Copernicus. (Nasmyth.)

actual craters of volcanoes. Their diameters are very large, 50, 100, and even 133 miles. The walls are steep and ragged, the interior slope often descending much deeper than the exterior. As one of these craters comes into sunshine, the slope opposite the sun is bright with light, while the bottom is dark in the shadow of the wall. A volcanic cone frequently rises from the bottom of a crater.

346. **Tycho** is a remarkable crater near the southern edge of the moon. In diagrams, which usually show the moon as it appears inverted in a telescope, this mountain appears near the top. Its diameter is about 54 miles; its walls are 16,000 to 17,000 feet high; a mountain rises from the

Fig. 119.—Mountains of the moon; region near Tycho. (Nasmyth.)

bottom of the crater, about a mile high. The region about Tycho is completely broken with ridges, peaks, and craters.

Tycho is notable for the great number of streaks of light which diverge from it in every direction, particularly to the north-east. They are so regular that they seem like meridians, and the mountain appears to be the lunar south pole. These bright lines are best seen at the time of full moon; they are not ridges, or they would cast shadows, when the sunlight is oblique to them.

347. **Rilles.**—These look like huge railway excavations,—two parallel slopes on either side of a deep sunken way. They are sometimes a mile and a half wide, from 1300 to 2000 feet deep, and from 10 to 125 miles long. Their dimensions, and the fact that they cut through mountain ridges

Fig. 120.

and craters, show that they can not be river beds. Carpenter and Nasmyth suggest that the rilles and the radial streaks about Tycho, Kepler, Copernicus, and other ring mountains, are the marks of cracks produced by internal convulsions, and illustrate by a photograph (Fig. 120) of a glass ball, cracked by the expansion of water within.

348. Active volcanoes.—In 1787, Herschel reported three active volcanoes in the moon. In 1794, two persons in different parts of England saw a bright spot, like a star of the third magnitude, upon the dark part of the moon's disc, the moon not having reached her first quarter. As the moon passed before the star Aldebaran on that evening, most astronomers suppose that star to be the spot seen.

During lunar eclipses bright spots have been seen, which were thought to be volcanoes. They have been explained as caused by earth-light reflected again from smooth surfaces of rock.

IS THE MOON INHABITABLE?

349. Has the moon water?—The gray places were first called seas and marshes, names which now seem inappropriate, as no evidence of water can be found. The sunlight reflected from sheets of water would reveal effects which could be recognized by the polariscope (309), but they do not appear. Prof. Mitchel describes a spot which has the appearance of a lake. From mountains which surround it, a sloping beach extends to the level surface. The highest magnifying power shows no roughness, and the shading is as regular as if the cavity were filled with ice or quicksilver. "This phenomenon," says Prof. Mitchel, "has baffled the most diligent and persevering efforts to explain."

350. Has the moon air?—The absence of twilight; the absence of refraction, when the light of a star passes near the surface of the moon; and researches with the polariscope and spectroscope all indicate that the moon has no atmosphere. Without air, the water, if any exists, must be in a state of vapor, as water evaporates in a vacuum; but there is no evidence of even vapor of water.

351. Is the moon inhabited?—Without air and water no form of vegetable or animal life which we know can exist.

Even if these conditions were satisfied, the slow rotation of the moon, alternately shutting off the sun's rays, and exposing plants and animals to their unmitigated fierceness for two weeks at once, would require organizations materially different from those found on the earth.

May not the rugged nature of the moon's surface show what the condition of our earth would be, without the air and water, which have worn down the ridges, filled up the chasms left by the earthquake and the volcano, and by a long series of geologic changes fitted the earth for the habitation of man?

THE ROTATION OF THE MOON.

352. **The moon always** shows the earth the same face, with little variation, save that from the changing shadows as sunshine comes from different directions. Hence we conclude that she turns on her axis once during each revolution. A person may readily illustrate the rotation of the moon by walking about a table, keeping his face always turned toward the central object. He will see that he looks toward every part of the room, or every point of the compass, successively, precisely as if he had turned once about in one place. The rotation coincides *exactly* with an average revolution. If not, the moon would gradually turn some other side to the earth, and ultimately would show her entire surface. We now see in the full moon, without a telescope, a rude sketch of a face,—eyes, nose, and mouth; ancient writers describe the same appearance.

353. **Librations.**—While, in the main, the moon always turns the same side toward the earth, she passes in her complex movements through certain changes of position, which resemble oscillations or vibrations, and, in consequence of these vibrations, we see occasionally small portions of the

opposite face of the moon. These changes are called *librations.* There are three, *libration in longitude*, *libration in latitude*, and the *diurnal libration.*

354. **Libration in longitude.**—The motion of the moon in its orbit is variable; that about its axis is regular. Hence, when the moon is in that part of its path where it moves slowly, the rotation gets a little in advance, and the moon shows a little of the opposite side on the east; in the opposite part of the orbit, the rotation does not keep up with the orbital motion, and we see a little farther on the west. As this is a result of the moon's variable motion in longitude it is called *libration in longitude.*

355. **Libration in latitude.** — The axis of the moon makes an angle of about 83½ degrees with its orbit. Hence, in one part of a revolution the north pole is turned toward the earth, in another it is turned away from the earth; in the first case it is possible to see 6½ degrees beyond the north pole; in the second, the same distance beyond the south pole. This result is precisely similar to the change of seasons as caused by the inclination of the earth's axis to its orbit, and to the rays of the sun. It is called *libration in latitude.*

356. **Diurnal libration.**—Were the center of the moon's visible face always turned exactly toward the center of the earth, the visible portion would even then be different to persons differently situated on the earth, and the same result accompanies the earth's rotation. The observer who sees the moon rise, is at the distance of the earth's radius west of this central line; when the moon sets, he is at the same distance east of that line, and the face turned toward him is slightly changed. This variation, of course, occurs every day.

357. From these three librations we obtain some knowledge of the remote side of the moon; we can see, at various

times, about four sevenths of the entire surface. So far as we can see, the remote side is not materially different from that turned toward us; it has neither the great cavity nor the great protuberance which have at times been suggested.

OTHER APPARENT VARIATIONS.

358. **The moon runs high or low.** — The moon is never more than $5° 9'$ from the ecliptic (336). In December, the sun's meridian point may be as much as $23\frac{1}{2}°$ below the equinoctial (53), and, therefore, the midnight meridian point of the ecliptic will be $23\frac{1}{2}°$ above the equinoctial, or for an observer at latitude $40°$, in altitude $50° + 23\frac{1}{2}° = 73\frac{1}{2}°$. Hence, if the the full moon at midnight should be $5°$ above the ecliptic, its altitude would be $50° + 23\frac{1}{2}° + 5° = 78\frac{1}{2}°$. It would then be only $11\frac{1}{2}°$ from the zenith.

In June, the full moon at midnight may have an altitude as little as $50° - 23\frac{1}{2}° - 5° = 21\frac{1}{2}°$.

It is also evident that the December altitude may be $10°$ less, and the June altitude $10°$ more than the numbers above found.

359. **Daily delay of moon-rise.**—An observer in north latitude sees the sun rise earlier, day by day, as it moves northward, or as its northern declination increases (136). In the same way, motion of the moon north in declination tends to make the moon rise earlier. But the daily eastward motion of the moon in its orbit delays its rising, as it delays its passage over the meridian (116), by an average of about 54 minutes. If the moon is at the same time moving northward, that delay may be reduced to 23 minutes; if southward, it may be increased to 77 minutes; it will rise so many minutes later than on the day before. These variations occur in some measure during every lunation.

360. The Harvest-moon.—The full moon which happens nearest the *time* of autumnal equinox, being in opposition to the sun, is near the *place* of the vernal equinox, and at the same time is moving northward. It is, therefore, increasing north declination daily, and, as just explained,

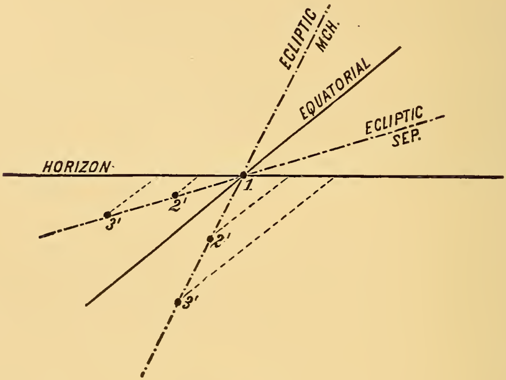


Fig. 121.

the daily delay in moon-rise is very small, so that the full moon rises for several successive nights with comparatively little variation in time.

Suppose the full moon in September to rise at the point 1 on a certain day. It will move forward in declination, that is, toward the left, and its path will be on or very near the ecliptic. At the end of twenty-four hours, it will be at the point 2, and will have to pass over only the short dotted line from 2 to reach the horizon; its rising will be delayed but little. On the third day, its delay in rising will be indicated by the short dotted line from 3 to the horizon. In March, its path will also be near the ecliptic, but in the position indicated, and the daily forward motion will bring it to the points 2′ and 3′, from which the longer dotted lines indicate much greater delay in rising.

As the principal harvests in England are completed about the time of the September full moon, this has been called the Harvest-moon. The next moon has something of the same peculiarity, and has been called the Hunter's moon.

361. **Light and heat of moon-light.**—The ratio of sun-light to that of the full moon is given by—

Bouguer,	at 300,000	to 1.
Wollaston,	at 800,000	to 1.
Zöllner,	at 619,000	to 1.

The latter determination is probably the best.

Delicate experiments upon high mountains indicate that the heat of moon-light, at full moon, is equal to that of an ordinary candle at a distance of 15 feet. Even this small amount is absorbed by the air before it reaches the earth.

362. **Visibility of small objects on the moon.**—The distance of the moon is 240,000 miles. A magnifying power of 1000 enables us to see the surface as it would appear at a distance of 240 miles; a power of 6000 would seem to bring the moon within 40 miles. But since light is diminished as magnifying power is increased (69), only moderate powers can, as yet, be used to advantage in studying the moon.

363. RECAPITULATION.

The different relative positions of the sun and earth cause the moon to change:

The time of synodic revolution;
The eccentricity of orbit;
The position of the line of apsides;
The position of the line of nodes.

Phases are seen when the side illuminated by the sun is viewed from different positions.

The ashy light of new moon is the reflection of light received by reflection from the earth.

The telescope shows plains, mountains, craters, rilles, but no evidence of water, air, or inhabitants.

Librations show alternately small parts of the moon's farther side. Motion in orbit which does not correspond to rotation causes libration in longitude; inclination of moon's axis, libration in latitude; the place of the observer, alternately east and west of the line which joins the centers of the earth and moon, diurnal libration.

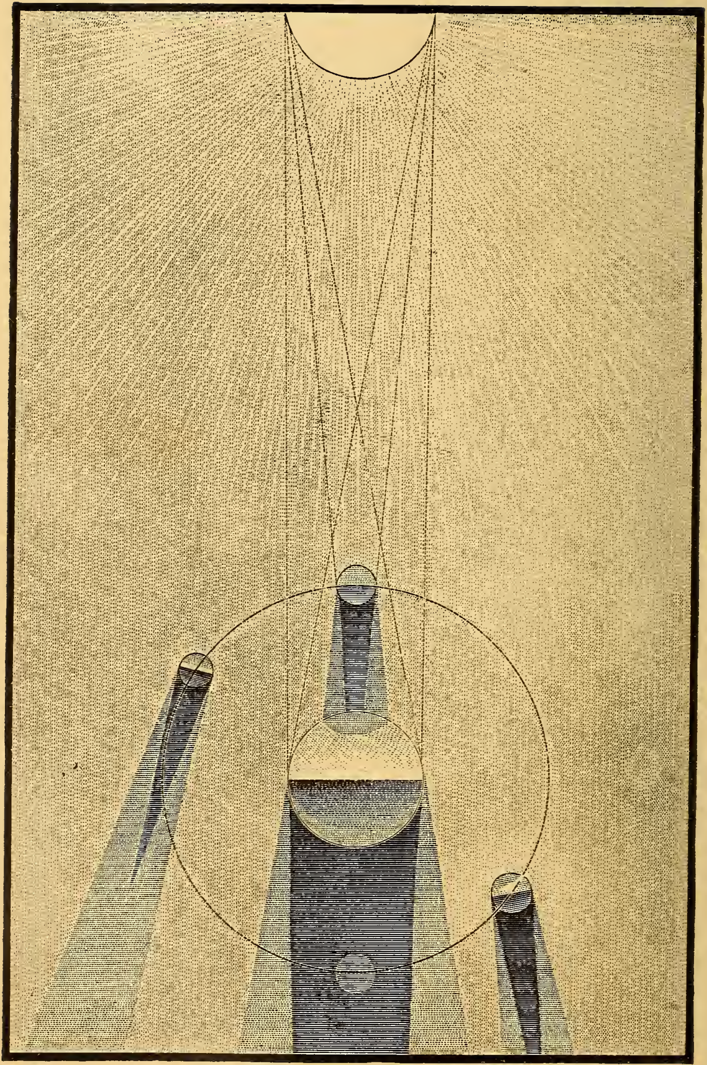


Fig. 122.—Theory of Eclipses.

F. 193.

CHAPTER XIV.

ECLIPSES OF THE MOON.

364. **The earth's shadow.**—The earth is an opaque body, and, therefore, intercepts all the sunlight which falls upon it, leaving a space beyond which is not illuminated. In the diagram, the two lines which touch the earth and the sun, on the same side of each, show the outline of a space beyond the earth which is without light; this is the earth's shadow. As the sun is larger than the earth, it is evident

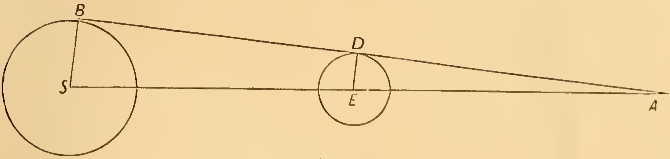


Fig. 123.

that the lines will meet, if sufficiently prolonged; hence, it appears that the shadow of the earth is a cone, whose base is nearly a great circle of the earth. The central line or axis of the shadow passes through the centers of the earth and sun, and is, therefore, in the plane of the ecliptic.

365. **The dimensions of the shadow.**—We find its length thus: The corresponding parts of the triangles *SBA* and *EDA* are in proportion; hence,

$$SB : ED :: SA : EA; \text{ or,}$$

$$433{,}000 : 4000 :: 93{,}000{,}000 + x : x, \text{ whence}$$

$x = 867{,}000$ miles, or about $3\frac{2}{3}$ times the distance to the moon.

By a similar proportion, the breadth of the shadow at the distance of the moon is found to be about 5800 miles, or about $2\frac{2}{3}$ times the diameter of the moon. But it must be remembered that the distance of the earth from the sun is variable, and, therefore, both the length and breadth of the earth's shadow vary in proportion.

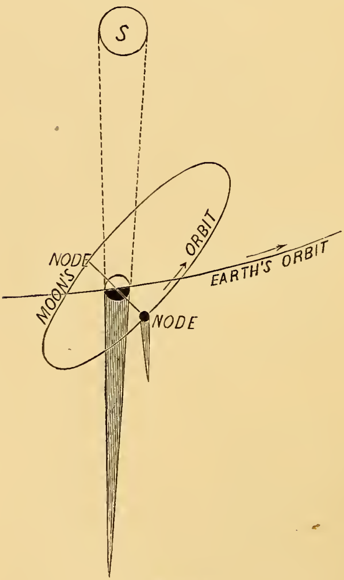


Fig. 124.

366. **The moon is eclipsed** whenever any part of its disc is darkened by the earth's shadow. If the shadow merely touches the disc, the contact is called an *appulse*. If the shadow covers only part of the moon, the eclipse is *partial;* when the moon passes entirely into the shadow, the eclipse is *total*.

Because the shadow is half above and half below the plane of the ecliptic, it is evident that the moon when eclipsed must be very near that plane, or, very near its node (336); and it is also evident that the moon must be in opposition (261). In Fig. 124 no eclipse occurs, because the moon is not in opposition. In Fig. 125 no eclipse occurs, because, although the moon is in opposition, it is below the plane of the ecliptic, not having yet come to the node.

If the moon's orbit lay in the ecliptic, an eclipse would occur at every opposition; if the line of nodes moved (336) with the syzygies (328), one might never happen.

As the shadow of the earth is about 5800 miles in diameter, the moon's surface must pass within about half that

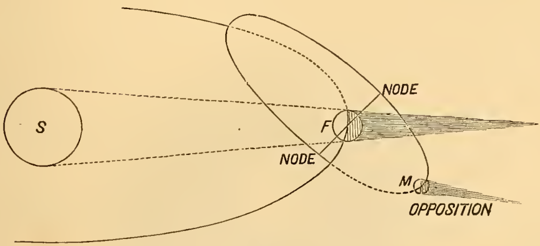


Fig. 125.

distance, 2900 miles, of the central line in order to insure an eclipse, and that requires that opposition be within about 12° of the node.

367. The earth's penumbra.—The earth's shadow is called the *umbra.* Lines which are tangent to the earth and sun (Fig. 123) on opposite sides of each, show the outline of the frustum of a cone, whose smaller base is nearly a great circle of the earth, and which stretches away indefinitely, in a direction opposite to the sun. This space is called the earth's *penumbra*, or partial shadow. Any object in this space loses part of the sun's light, intercepted by the earth. When the moon enters this reversed cone of partial shadow its light gradually wanes, until the sun's rays are quite cut off as the moon enters the cone of total shadow. The penumbra is about 9800 miles broad at the moon's distance.

368. The moon visible when eclipsed.—Even when totally eclipsed, the moon's disc usually shows a dull red or coppery light. This can not be caused by sunlight reflected

from the earth, like the ashy light of the new moon (341). for the illuminated side of the earth is turned from the moon. It comes from rays of sunshine bent about the earth by passing through the atmosphere (124). In some cases the red light does not appear, and the moon becomes quite invisible; at

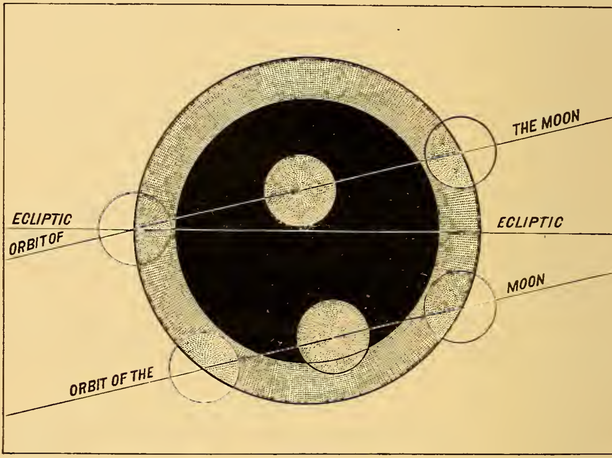


Fig. 126.

other times the light is very much diminished; the difference is due to the state of the air where the bent rays pass the earth.

369. The eclipsed moon has been seen before sunset. This would seem to be contrary to the theory of eclipses, since it would imply that the three bodies were not in the same line, both sun and moon being above the horizon. But it will be remembered that all bodies near the horizon are elevated by refraction (124), and that for this reason both sun and moon are visible when they are actually below the plane of the horizon; hence, it has happened that the moon rose in eclipse just as the sun was setting.

370. Occultations.—The disc of the moon not infrequently passes over and hides a star or planet which is then said to be *occulted.* From new to full moon the stars disappear at the dark side of the disc, as that side is foremost in the moon's motion; from full to new, they disappear on the bright side and re-appear on the dark side.

371. Diagrams.—In all astronomical subjects it is difficult to show correct relations of size in diagrams, or by apparatus. The figure shows the proportion of the earth's shadow, the moon just going into eclipse. The sun must be understood to be represented by a globe 5½ inches in diameter, and about 49 feet distant.

Fig. 12

ECLIPSES OF THE SUN.

372. The moon's shadow.—The moon, like the earth, carries on the side opposite the sun, a cone of shadow and a conical penumbra. The length of the moon's shadow varies with the relative position of the two bodies; it averages 231,690 miles, a little less than the average distance of the moon. When the earth is at aphelion and the moon at perigee (210) the shadow is long enough to reach about 14,500 miles beyond the earth's center, and covers a space on the earth about 170 miles in diameter. When the earth is at perihelion, and the moon at apogee, the shadow does not reach the earth; the earth passes through only the partial shade of the penumbra.

373. Solar eclipse.—A person in the cone of shadow sees no part of the sun. To him the sun is *totally* eclipsed, or, to speak more exactly, *occulted*, hidden, by the moon. A person in the penumbra

will see the moon cover a part of the sun's disc; to him the sun is *partially* eclipsed. When the shadow is not long enough to reach the earth, the lines which define it being prolonged beyond the apex form a second, reversed cone. A person in this cone will see the sun's disc surround the moon with a ring of light; the eclipse is *annular*. If the observer is also on the line which joins the centers of the sun and moon, that is, on the axis of the moon's shadow, the eclipse is *annular and central*.

The same eclipse may show all these forms at different places, as the shadow of the moon sweeps over the earth's surface. The shadow may be long enough to reach the surface, but not the center of the earth; then the eclipse will be annular to those who see it near sunrise or sunset, and total to such as see it near midday. The space in which the eclipse is either annular or total is surrounded by a belt, of width varying at different occasions, in which the eclipse is partial.

374. **Baily's beads.**—Most of the phenomena of a solar eclipse have been described in the chapter on the sun. As the bright thread of light between the dark edge of the moon and the edge of the sun vanishes, it is often divided into many bright points, called from their first observer, Baily's beads. They are thought to be caused by rays of sunlight streaming through gaps in the ragged mountain ranges of the moon. They will be observed most readily at that part of the moon's disc where the mountain chains are most broken.

375. "The intensity of the illumination of the atmosphere naturally diminishes during the entire duration of a total eclipse, from its commencement until the beginning of its totality, to again as gradually recover its primitive intensity. This obscurity, during the phase of totality, is, however, far from being complete. Thus only the brightest stars, and some of those of the second magnitude, are seen. The

planets, Mercury, Venus, Mars, Jupiter, and Saturn, however, have been likewise observed.

"Terrestrial objects take by degrees a livid hue; they are colored with various tints, among which olive-green predominates. Orange, yellow, vinous-red, and copper tints, give to the landscape a singular appearance, which, joined to the very perceptible lowering of the temperature, contributes to produce a profound impression on all animated beings."

376. **Rate of motion of the eclipse shadow.**—The moon moves in its orbit at the rate of about 2080 miles an hour, while the surface of the earth at the equator moves, in consequence of rotation, 1040 miles an hour, in the same direction. Hence, the moon's shadow moves over the surface of the earth at the equator, $2080 - 1040 = 1040$ miles an hour. When the axis of the shadow is oblique to the surface, or is received at some distance from the equator, it moves more rapidly.

FREQUENCY OF ECLIPSES.

377. **Solar.**—A lunation (329) averages 29 d. 12 h. 44 m. 3 sec. $= 29.53 +$ days. There are, therefore, $365.25 \div 29.53 = 12.4$ lunations in one year. The distance on the ecliptic from one conjunction of the sun and moon to the next, is $360° \div 12.4 = 29°$. A solar eclipse may occur when conjunction is within 18° of the node (App. VII). The next conjunction being 29° farther advanced, or $29° - 18° = 11°$ beyond the node, is also within the ecliptic limit, and a *second* solar eclipse occurs.

The nodes move westward (337), making one revolution in 18.6 years, or $18.6 \times 12.4 = 230.64$ lunations; hence, their motion is $360° \div 230.64 = 1.56°$ for one lunation, or 9.36° for six lunations; hence, the second node is $180° - 9.36° = 170.64°$ in advance of the first. Now the seventh conjunction will be $6 \times 29° = 174°$ in advance of the first

conjunction, or $174° - 18° = 156°$ in advance of the first node, or $170.64° - 156° = 14.64°$ behind the second node. But this is within the ecliptic limit, causing a *third* solar eclipse.

The next, or eighth conjunction, 29° farther on, is 14.36° beyond the second node, and causes a *fourth* solar eclipse.

The first node, by reason of the backward motion, or precession of the nodes, will be found again at 341.28° from its first place; while 12 lunations will carry the 13th, 348° from the first conjunction, and as the first conjunction was 18° behind the first node, the 13th will be $348° - 18° = 330°$ in advance of the first node, or within $341.28° - 330° = 11.28°$ of the second place of the first node. This is again within ecliptic limit, and causes a *fifth* solar eclipse. The 13th conjunction occurs in 12×29.53 days $= 354.36$ days, or about 11 days less than one year; hence, the five solar eclipses described *may* occur within one year.

378. **Lunar.**—Two lunar eclipses can not occur in two consecutive months, since the lunar ecliptic limits possibly extend only $2 \times 12°\ 24' = 24°\ 48'$ in length, while the motion of the place of opposition, like that of conjunction, is 29° in a lunation. The seventh opposition is $6 \times 29° = 174°$ in advance of the first, and as the second node is 170.64° in advance of the first, the seventh opposition has gained 3.36° *relatively to the nodes*, and may be again within the lunar ecliptic limit.

Thus, if an eclipse of the moon happens at 12° behind the first node, a *second* will occur $12° - 3.36° = 8.64°$ behind the second node, and a *third*, 5.28° behind the third node; and, as the three nodes may all be passed in 346.62 days, three lunar eclipses may occur in one year.

379. **The number possible in one year.**—The place of opposition follows that of conjunction in 14.5° on the ecliptic. Hence, if a solar eclipse is more than $14.5° - 12.4° = 2.1°$ behind the first node, a lunar eclipse *may* occur

at the next conjunction, since that will be within the possible ecliptic limit. Hence, in the case supposed, in Art. 377, the first, third, and fifth solar eclipses will each be followed by a lunar eclipse within 15 days.

As only about eleven days of the year remain after the fifth solar eclipse, there is not time enough for the next lunar eclipse to happen within that year. Hence, the greatest number of eclipses possible in one year is *seven*, of which *five* are solar, and *two* lunar.

The least number of eclipses possible in one year is two, both of the sun.

Lunar eclipses are visible to the entire hemisphere turned to the moon; solar eclipses are only visible at those places on the earth which enter the moon's shadow. Hence, although solar eclipses are most numerous, lunar eclipses are oftenest seen at any given place.

380. The Saros.—Eclipses occur only when the sun and moon are in conjunction or opposition near one of the moon's nodes. Conjunction is repeated at intervals of 29.53 days; the sun passes the same lunar node at intervals of 346.62 days. Whenever these intervals end on the same day, conjunction will have the same relation to the node which it had at first, and an eclipse of the same nature will happen. Now, 223 intervals bring a conjunction in 6585.19 days, and 19 intervals bring the sun to the same node in 6585.78 days. But 6585.19 days equal 18 years 10¾ days; hence, after that period of time, the cycle of eclipses will return again, the eclipses being repeated with the same general characteristics, but some hours later in the day, and, therefore, visible at different places. This period, called the *saros*, was known to the ancient Chaldeans, who predicted eclipses by it. In it there are usually 41 solar and 29 lunar eclipses. It is not perfectly accurate, by reason of the various disturbing causes which modify the moon's orbit, but it serves to direct the attention of astronomers to the most important eclipses.

381. **The golden number** is not to be confounded with the saros. In Pagan and Jewish rituals certain ceremonies were to be observed at certain times of the year, and during particular phases of the moon. In the Christian church the time of Easter is similarly found. Meton discovered that 235 lunations are completed in 19 years (235×29.53 days $=$ 6949.55 days, and 19×365.2422 days $= 6949.60$ days); it is only necessary to record the dates of one cycle of lunar phases for 19 years, to know them for the same days of the year during each subsequent period. The Greeks deemed this discovery of such importance that they ordered the number to be inscribed on their public monuments in letters of gold.

382. RECAPITULATION.

The earth's shadow is a cone about 860,000 miles long, and, at the moon's distance, 5800 miles wide; the *penumbra*, at the same distance, is 9800 miles wide.

The moon's shadow is about 230,000 miles long; at some times more, at others less, than the distance to the earth.

The moon is *totally* eclipsed when it passes entirely into the earth's umbra; otherwise, the eclipse is *partial.*

An eclipse of the sun is *total* to a person in the moon's *umbra; partial* to one in the *penumbra; annular* to one in the *penumbra* and within the *lines of the umbra.*

Eclipses possible in one year:

	Greatest No.	*Least No*
Solar,	5	2
Lunar,	3	0
Both,	5 S + 2 L	2 S

The *Saros;* the time after which eclipses are repeated in similar order: 18 years $11\frac{1}{3}$ days.

The *Golden Number;* the time after which the phases occur on the same days of the month: 19 years.

CHAPTER XV.

THE TIDES.

383. **Definitions.**—The alternate rising and falling of the waters of the ocean, twice in every lunar day of about 25 hours, are called *tides*. The rising water is *flood tide*, and the highest level reached, *high water;* the falling water is *ebb tide*, and the lowest level reached, *low water*. The farthest line of the beach which the receding waters at any time disclose, is *low-water mark*.

At the time of new and of full moon, high tides are above the average, and are called *spring tides;* at first and last quarters, they are below the average, and are called *neap tides*. When high water is highest, low water is lowest, and conversely.

The spring tides are generally from once and a half to twice the height of the neap tides.

384. **The tides are caused by the sun and the moon.**—From the fact that high tide each day follows at rather regular intervals after the passage of the moon over the meridian, and that spring and neap tides occur at certain phases of the moon, we infer that they are in some way connected with the motions of that body, and caused by its influence.

But the tides vary not only at different times of the month, but at different seasons of the year. They are highest of all at the time of the equinoxes, and high tide is lowest at the

time of the solstices; the tides of the summer solstice are lower than those of the winter solstice. Hence, we infer that the sun has also an influence modifying the rising and falling of the waters. The ancients understood so much, but the nature of the influence was to them unknown. Pliny wrote "*Causa in sole lunaque;*" the cause is in the sun and the moon.

THE EARTH'S SHAPE AFFECTED,

385. **First, by terrestrial gravitation.** — We have learned (161) that the earth, if at rest, and influenced only by the mutual attraction of its particles, would assume the shape of a perfect sphere. Each point on its surface would be equidistant from the center, not because the center has any peculiar attractive force, but because in this spherical shape all the attractions in one direction are exactly counterpoised by the attractions in the opposite direction.

386. **Second, by rotation.**—We also found that when the earth rotates on its axis, the tangential force of the particles near the equator, where the motion is most rapid, opposes the attraction of the rest of the sphere, or the attraction of gravitation; that in some degree the weight of those particles is diminished, and, therefore, the shape of the earth changes until the longer column of lighter matter at the equator is balanced by the shorter column of heavier matter near the pole; remembering that the same matter may be heavy or light, as it receives more or less attraction.

Fig. 128.

387. **Third, by an external attraction.**—Let *A*, *B*, *C*, *D*, and *E*, be several particles of matter in a line, and

suppose them attracted by a mass, *X*, at some distance on that line, acting in accordance with the known laws of gravitation (158). The nearest particle, *A*, is drawn more than the others; *B*, next; *C*, next, and so on, the force on each particle being less as the square of its distance from *X* is greater. If there were no opposing force, each particle would obey the impulse given to it, and would move at a rate proportioned to the force of attraction, *A* going fastest, *B*, next, and so on. But if other forces oppose, the particles will still *strive* to move, and will be prevented only when a part of the opposing force, equal to this external attraction, has been exhausted. The effect of the external force, in either case, will be to draw the particles away from each other, along the line *EX*, into the new positions A^1, B^1, etc. That is, their mutual attraction for each other, if they have any, will be weakened.

388. Illustration. — Thus, suppose three boys, John, Charles, and Henry, of various strength, join hands and run along the street; the strongest naturally goes fastest; the weakest, slowest. John, stronger than Charles, will pull

Fig. 129.

away from him; Charles, stronger than Henry, will do the same, but will quite likely complain of Henry for holding him back, while, in fact, the little fellow is doing all he can to keep up. So, although all are earnestly striving in the same direction, the first and last boy seem each to be pulling away from the boy in the middle.

389. Now, let C be the earth's center, and A and B, two particles at opposite ends of a diameter which points toward some external attracting force, say the moon, M. Their mutual attraction is weakened by the external unequal attraction of the moon. But the mutual attractions of P and R, on a line perpendicular to AB are not diminished, since

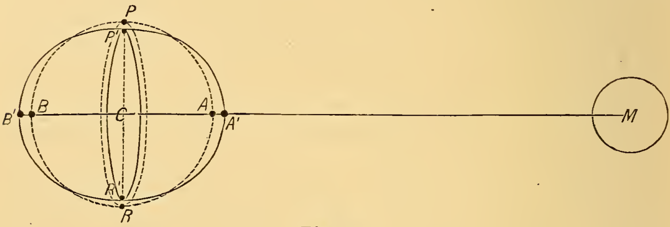


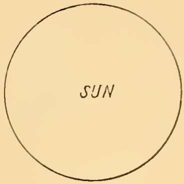
Fig. 130.

they are equally distant from the moon. In fact, as they are outside the central line of the moon's force, it tends to draw them into that line, and, hence, to increase their mutual attraction. The same is true of all the particles in the circle PR, which is perpendicular to the line AB. Now, as AB is prolonged, becoming $A'B'$, and PR is contracted, becoming the circle $P'R'$, the shape of the earth becomes elongated, or melon-shaped, a *prolate spheroid.*

390. **The place of the center** is not changed, because the motion of the moon, in its path, keeps the distance between the two bodies the same. Hence, as the position of the center is not disturbed, and the diameter of the earth has been prolonged, it follows, paradoxical as it may seem, that the attraction of the moon upon the mass of the earth has forced B farther from the center. In the same way the waters are heaped up on the side opposite to the moon as well as on that next to it.

391. **The sun's attraction** produces a similar effect. But it must be remembered that the effect in the case of the

moon is not due so much to the absolute amount of the moon's attraction, as to the fact that the attraction is greater on one side than on the other, owing to the relatively greater distance. The sun's distance from the opposite side of the earth, although greater, is not relatively as much larger, as in the case of the moon, and, hence, the difference of the attractions is not as great. The force of the sun to raise a tide is to that of the moon in about the ratio of 2 to 5.



VARIATION OF TIDES.

392. **Spring tides and neap tides.**—At new moon, the sun and moon, being on the same side of the earth, act in concert. At full moon, although they act in opposite directions, each tends to elongate the same diameter of the earth; hence, the results of the attractions are combined, and the direct tide of each assists the opposite tide of the other. In either case spring tides result (Fig. 131).

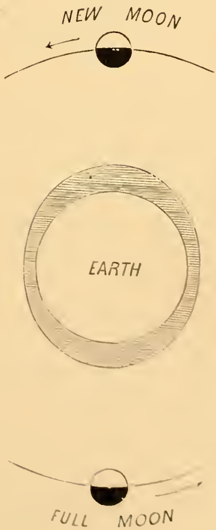


Fig. 131.

At the quarters, the moon's high water is in the place of the sun's low water; each draws down the tide of the other, and neap tides result (Fig. 132).

When both sun and moon are north of the equinoctial, as in our summer, the highest part of the direct tide-wave is north of the equator, and of the opposite tide-wave, south of the equator; during our

winter, the converse is true. Hence, in summer the spring tide of the day is higher than that of the night following.

Highest tides occur when both bodies are near the equinoctial; hence, the extreme height of the tides at the time of the equinoxes.

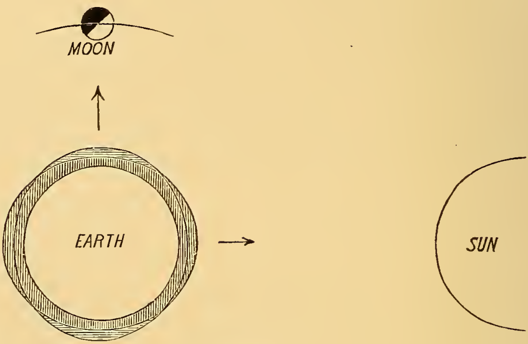


Fig. 132.

393. **Inertia delays the tide.**—Considering the lunar tide by itself, we look for high water directly under the moon, or, at the place where the moon is on the meridian; as one meridian after another passes the moon in the daily rotation of the earth, the tide-wave should move westwardly round the earth. But on account of inertia the water can not instantly obey the moon's force, and, therefore, high water follows a few hours after the moon's culmination, the time varying at different ports with the peculiar circumstances of the location. The time which regularly elapses at any place, between the moon's culmination and the time of high water, is called the *establishment of the port.*

Lines drawn on the map through the various points which are reached by the tide at the same hour, are called *co-tidal lines.*

It must not be supposed that the water moves about the earth; only the rising, or the wave, moves. Shake a carpet

on the ground; a series of swells and depressions runs from the hands through the cloth and vanishes at the farther side. The waves run through the carpet; the cloth moves up and down, but does not move forward.

394. **Priming and lagging of the tide.** — When the solar and lunar tide-waves are near each other, high water coincides with neither, but falls between the two. Hence, if the lunar tide follows the solar, as happens just after new or full moon, high water comes a little earlier than the usual time fixed by the establishment of the port; if the lunar tide precedes, as just before new or full moon, high water is delayed, or lags.

395. **Origin and motion of the tide-wave.**—The tide-wave begins in the great Pacific Ocean. Its general course is westward, its rate varying with the breadth and depth of the water which it traverses. Its velocity is retarded in narrow and in shallow places. It enters the Atlantic at the Cape of Good Hope, and follows the winding channel northward until it is turned eastwardly at the Banks of Newfoundland and Labrador, and is expended on the north-west coasts of Europe. Beginning near South America, the tide reaches

Kamtchatka,	in	10	hours.
New Zealand,	"	12	"
Cape of Good Hope,	"	29	"
United States,	"	40	"
Western Ireland,	"	44	"
London,	"	66	"

The time from Western Ireland to London is used in flowing round the north coast of Scotland, south through the North Sea, and up the Thames.

396. **Height of tides.**—At the islands of the Atlantic and Pacific oceans the average height of the tide is only

about 3½ feet. On the west coast of South America it is 2 feet. As the wave approaches the east coast of Asia, where the depth diminishes, it finds less room to move in, and, therefore, rises higher,—not less than 4 or 5 feet.

A wave which enters a bay through a narrow opening is spread over the wider space beyond, and may entirely vanish; hence, the oceanic tide produces no effect in the Mediterranean Sea. If the wave flows by a broad channel into a bay whose breadth constantly contracts, or into the estuary of a river, the want of width will cause an increased height. The tide rises at

Long Island Sound, East end,	2	feet.
" " " West end,	7	"
Mouth of St. Lawrence,	9	"
Quebec,	20	"
Boston,	10	"
Bay of Fundy, entrance,	18	"
" " head of bay,	70	"

The great tide-waves of the ocean are called *primitive tides;* those which run from them up bays, estuaries, and rivers, are *derivative tides.*

The motion of a tide-wave up a river is necessarily slow, as it is delayed by the shallow water, by the narrow channel, and by the opposing current. The tide flows from New York to Albany in about 9 hours, moving at the rate of 16 miles an hour.

397. **Local tides.**—As remarked, the oceanic tide does not enter the Mediterranean; it has a tide of its own, however, averaging about 1½ feet. The length of the sea, 2400 miles, is about one third the diameter of the earth, and its tide is about one third that of the ocean.

The tides in the Great Lakes are too small to be easily observed. A series of observations at Chicago, indicate a

tide of 1¾ inches, about 30 minutes after the moon's culmination. Here, also, the height of the tide is to that of the oceanic tide, as the length of the lake is to the diameter of the earth.

DOES THE MOON INFLUENCE THE WEATHER?

398. **Tides in the air.**—As the air is material, it should obey the moon's attraction as well as the water. But the air flows in no narrowing channels or estuaries like those which condense the oceanic tide; whatever wave it has must be compared with the lowest tide-wave in the open sea. The only evidence of an aerial tide will be derived from the varied pressure of the air, as indicated by the barometer. But the tide exists only to restore the balance of pressure which has been disturbed by an external attraction. The longer column of air under the moon at high tide should not press more heavily than the shorter column at low tide, because it is precisely the lifting power of the moon which causes any difference in height. As we should expect, therefore, the change in the mercury of the barometer due to the aerial tide is very slight, if any,—less than .001 of an inch.

399. **Influence of the moon on clouds.**—An opinion prevails to some extent that moonlight disperses clouds: sailors say "the moon eats the clouds." The opinion may be defended. The full moon reflects a little solar heat, which may have a slight effect to expand vapor, and dissipate clouds.

400. **Influence of the moon on rain.**—Observations continued during 28 years, in and near Munich, in Germany, gave the number of rainy days in the growing, to the number in the waning, moon, as 845 is to 696, or as 6 is to 5, nearly. This would indicate that it rains oftenest in the first half of the month. Similar results were obtained at Paris. Observations made for 10 years, at Montpellier, in the south of

France, found 9 rainy days in the growing moon to 11 in the waning moon, a result opposite that found at Munich, only about 300 miles distant. The results in either case indicate coincidences, not consequences. More proof is needed before it can be admitted that the moon influences rain.

401. Wet and dry moon. — Equally valueless is the tradition that the crescent of the new moon, when nearly horizontal, foretells a dry month; or, when nearly vertical, a wet month. As with most "signs," those who accept them do so from coincidences observed; cases which prove the sign are noted; those which do not, are neglected; we are convinced because we wish to be convinced. The nearly horizontal crescent happens whenever the plane of the moon's orbit is in such a position as to carry the moon past conjunction above the sun; the vertical crescent in the opposite case; the changes from one to another are slow and gradual. There can be nothing in either to affect temperature, or moisture; that is, to cause, or prevent, rain.

402. Influence of the moon's changes on changes of the weather.—As before, the records of the few reliable series of observations give contradictory results. At Vienna,

100 new moons gave	58	changes	of	weather.
100 full moons,	63	"		"
100 of each quarter,	63	"		"

This indicates that the new moon brings fewest changes of weather, which is *contrary* to tradition.

Toaldo, at Venice, found that six new moons out of every seven brought changes of weather, but he included any change which happened within two days, either before or after the day, of new moon, actually counting *five days*. Had he added another day on each side, his results would have been still more striking, for more changes are likely to occur in seven days than in five. In the changeable climate of the temperate zone, we can not count on changeless

weather for five days together at any time of year, and if we were to selcct any five days of the month for observations, we should find a majority bring change.

All scientific investigation indicates that the moon has no influence on the weather, and that no forecast can be made by it.

The traditions which teach the time of the moon in which to sow, to plant, to kill pork, to cut timber, etc., are all too absurd to be refuted.

403. RECAPITULATION.

Influenced by *terrestrial gravitation* alone, the earth would be an *exact sphere; rotation* added, shortens the polar diameter, making the sphere *oblate;* an *external attraction* lengthens the diameter which has the direction of that attraction, and tends to make the sphere *prolate.*

Tides are caused by the attractions of the *sun* and *moon* acting with forces in the ratio of 2 to 5; acting in the *same line*, they cause *spring* tides; at *right angles*, *neap* tides.

Tides originate in the Pacific Ocean; they pass through the Indian to the Atlantic Ocean in about 30 hours.

The height varies inversely as the amount of sea-room from 2 to 70 feet. Large inclosed bodies of water have local tides.

There is no evidence of tides in the air, or that the changing moon influences rain or the weather.

CHAPTER XVI.

THE PLANETS.

404. **Is there a planet** between Mercury and the sun? The possibility was first suggested by Leverrier. He thought that the attraction of such a body might be the cause of certain known irregularities in the motions of Mercury. On a few occasions observers have reported the passage of a dark body before the sun's disc, which might perhaps be such a planet. During solar eclipses such bodies have been eagerly sought. In that of 1878, Watson reported that he had seen two small planets quite near the sun.

Although for more than forty years the sun has been an object of assiduous and most careful study, by methods which could scarcely fail of detecting such bodies, none of the supposed observations have ever been verified. Watson's objects were probably stars known to be near the places he assigned to them. It is not now believed that any bodies exist between the orbit of Mercury and the sun, worthy to be dignified with the name planet.

MERCURY.

SIGN ☿, REPRESENTING A WAND.

405. **Visibility.**—This planet is rarely seen without a telescope, because it never departs more than 29° from the sun. Copernicus mourned that he should go down to his tomb, having never seen it. The Egyptians knew it; the

Greeks called it Apollo, when visible in the morning, and, at night, Mercury, the god of thieves. At its greatest elongation (270), it may sometimes be seen for about fifteen minutes, about three quarters of an hour after sunset, or shortly before sunrise, appearing like a star of the fifth to the third magnitude (514). It may be seen for a few days before and after the following dates in 1885: April 8, Aug. 1, Dec. 1. The dates for subsequent years may be found by subtracting 18 days per year from those given; thus, in 1886, we find July 14; in 1887, June 28, etc.

In the telescope, Mercury shows phases like the moon, whence we conclude that it shines by reflecting the light

Fig. 133.—Phases of Mercury.

of the sun. It is most brilliant when near its greatest elongation; at superior conjunction, although the whole illuminated disc is turned toward the earth, distance makes the disc small; near inferior conjunction, only a narrow line of light is shown to the earth; in either case, its light is overpowered by the light of the sun.

406. The orbit of Mercury. — The greatest distance from the sun may be found from the greatest elongation (270) to be 43,300,000.

The sidereal period has been found to be nearly 88 days (268). By Kepler's third law (274),

$365\frac{1}{4}^2 : 88^2 :: 93{,}000{,}000^3 : 36{,}000{,}000^3$, the cube of the mean distance from the sun.

43,300,000 — 36,000,000 = 7,300,000, the eccentricity in miles = 0.206 of the mean radius vector. Hence, the least radius vector = 28,700,000 miles.

The eccentricity of Mercury's orbit is much greater than that of any other principal planet.

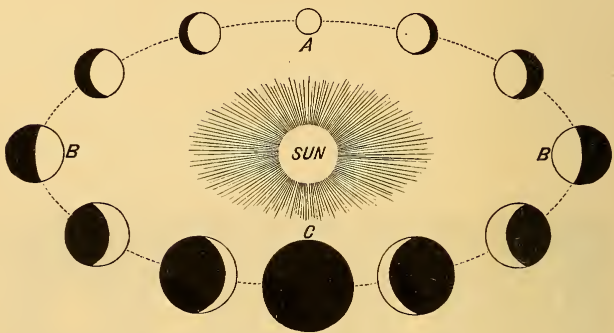


Fig. 134.

The plane of the orbit makes an angle of about 7° (7° 0′ 7.7″) with the plane of the ecliptic.

The planet's average velocity in its orbit is 29.55 miles per second.

407. **Transits of Mercury** are governed by laws precisely similar to those which control eclipses of the sun. They can occur only when the sun, Mercury, and the earth are in the same straight line; that is, when the planet comes to inferior conjunction near one of its nodes.

The sun passes the ascending node about the 4th of May, and the descending node about the 7th of November; transits must, therefore, occur near one of these days.

As the angle of the node is 7°, and the sun's apparent radius is 16′, the limits in longitude of a transit are about 2° (App. VII).

A synodic revolution occupies about 116 days (273), and in that time the sun appears to traverse (266) $116 \times 0.9856° = 114.5°$. If, then, we inquire if a transit will be repeated in 3 years, for example, we find that in three years the sun will have traversed $3 \times 360° = 1080°$. $1080° \div 114.5° = 9 +$ a remainder of 49.5°; hence, the node is 49.5° beyond the 9th conjunction, and a transit can not occur.

In 6 years the node is within 15.5° of the 19th conjunction, but because Mercury's orbit is very eccentric, its rate of motion is quite variable, and the time of a synodic revolution may at times be considerably less than 116 days; hence, the small arc of 15.5° may disappear, and the conjunction may be near enough to the node to cause a transit.

7 and 13 years are periods at which the two points coincide most nearly, and, therefore, are most likely to bring transits of Mercury at the same node; on account of the variation in the time of the synodic revolution, even these can not be relied upon, except after more intricate and exact computation. In 217 years the entire round of changes is complete, and the transits recur in regular order. The next transits occur May 9, 1891; November 10, 1894.

408. **Shape, size, and rotation.**—The most careful observations fail to detect any flattening at the poles of this planet. Its horizontal parallax, computed from its distance (284), and its apparent diameter, give its real diameter about 3000 miles, or about three eighths that of the earth. When compared with the earth, its volume is about .054; its mass, .065; its density, 1.21.

409. **Physical constitution.**—Because this planet is so near the sun, it is observed with great difficulty. The statements of the older observers are not substantiated by those who use the perfected instruments of the present day. Schroter gave the time of rotation at 24 h. 5 m., but this is not confirmed. If it be true, the planet's year has about 86 solar days.

Measures of the light of Mercury at its various phases have led Zöllner to conclude that there is no air present sufficiently dense to reflect sunlight.

The intensity of solar light and heat, endured at Mercury, varies with its varying distance from the sun, averaging nearly 7 times that received at the earth. At aphelion this amount is reduced to 4½, and at perihelion increased to 10 times.

VENUS.

SIGN ♀, A MIRROR.

410. Appearance.—The appearance of Venus, both in and without the telescope, its alternate shining as morning and evening star, its phases, and its transits, have already

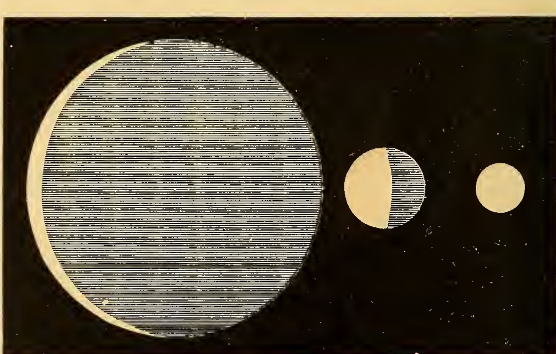


Fig. 135.—Phases of Venus.

been described (252). When most brilliant, it is about 40° from the sun. At inferior conjunction, though nearest the earth, its illuminated face is turned from the earth; at superior conjunction, its light is diminished by its great distance. Once in eight years, its position relative to the earth and the

sun is such as to cause a maximum of brightness; at such times it occasionally casts a sensible shadow at night, and may be seen during full sunshine.

411. **Orbit.**—The dimensions of the orbit may be computed, as in Art. 270; the greatest elongation being $47\frac{1}{2}°$. The mean radius is 67 millions of miles; eccentricity, 450,000 miles, or .0068 of the mean radius, showing that the orbit is nearly circular. The plane of the orbit makes an angle of about $3\frac{1}{3}°$ ($3° \ 23' \ 35''$) with the plane of the ecliptic. The synodic revolution is completed in 583.9 days; the sidereal, in 224.7 days. The rate of motion in the orbit is 21.61 miles per second.

412. **Transits of Venus** are specially important for determining the solar parallax (277–281). As the nodes are $75\frac{1}{3}°$ and $255\frac{1}{3}°$ from the vernal equinox, the sun passes those points early in June and December, and transits must occur in those months. The intervals between transits may be found as in Art. 406; or, thus:

The earth, or the sun apparently, passes the same node at intervals of $365\frac{1}{4}$ days; Venus, at intervals of 224.7 days. Eight revolutions of the earth are completed in 2922 days, and thirteen of Venus in 2921.1 days; at the end of eight years, the two bodies will pass the same point within 24 hours, and may cause a transit. 235 years of the earth coincide still more nearly with 382 years of Venus; and if a transit should not happen at the end of 235 years, one will be quite sure to occur eight years later. In 105 or 113 years after a transit at one node, another may be expected at the opposite node.

Transits of Venus were observed December 4, 1639; June 5, 1761; June 3, 1769; December 9, 1874; December 6, 1882. The next transits will occur June 8, 2004; June 6, 2012.

413. **Dimensions of Venus.**—Its diameter (283) is about 7700 miles, not much less than that of the earth. No

polar compression has been observed. The diameter is not easily measured on account of what is called the *irradiation.* If two circles of the same size are drawn, the one white on a black ground, the other black on a white ground, the white

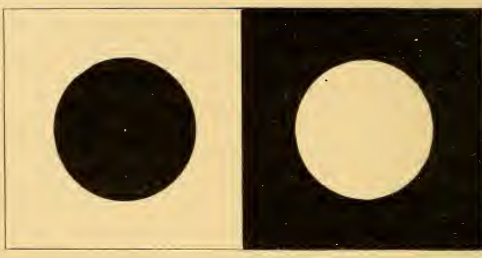


Fig. 136.—Effect of Irradiation.

circle will appear the larger, and the effect will increase with brilliancy of the white circle. The brightness of Venus produces this effect.

414. **Rotation.**—So lately as 1842, De Vico thought that he had determined the rotation by observing the motion of irregularities in its surface, and reported a sidereal day of 23 h. 21 m. 23 sec., of which 231 would complete one of the planet's years. Its mean solar day would then have 23 h. 27 m. 28 sec. of terrestrial time, or 32½ minutes less than one of our days. It is now doubtful if the rotation has ever been observed.

415. **Atmosphere.**—When Venus is nearly between us and the sun, the fine crescent on the side next to the sun seems to be continued in a complete thin circle of light about the whole disc. This can be explained only by supposing that the light has been refracted by an atmosphere. A similar effect has been seen at the time of a transit, and when the dark side of the planet is turned toward the earth as it is passing the node. The atmosphere is thought to be somewhat denser than that of the earth. Some observers believe

that the atmosphere is filled with dense clouds; others, that white patches have been seen near the supposed place of the planet's poles, such as will be described for the planet Mars.

416. **A Satellite.**—Its existence has been affirmed and denied. Several observers claim to have seen a small, bright crescent near the planet, and have even computed its size, volume, and time of revolution. The best modern observers can not find it, and insist that those who reported it were deceived by reflections of the planet from the surfaces of the lenses of the telescope. Such appearances are known to observers as "ghosts," and are troublesome to the inexperienced. A satellite might show itself at the time of a transit, if it were near enough to the planet to be projected upon the sun's disc at the same time.

THE EARTH, VIEWED ASTRONOMICALLY.

SIGN ⊕, A CIRCLE CROSSED BY EQUATOR AND MERIDIAN.

417. An observer looking from without upon the solar system, as upon a vast machine, would see a planet, nearly 8000 miles in diameter, revolving next beyond the orbits of Mercury and Venus, in an elliptical orbit, at a mean distance from the sun of 93 millions of miles, and at a rate of 18.38 miles a second; rotating once in a little less than 24 hours; its axis at an angle of $66\frac{1}{2}°$ with the plane of its orbit; shining by reflected light; its surface showing the hue of water, broken by the outlines of two great, and many smaller, masses of land, often rugged with mountains and volcanoes; its poles surrounded with spaces of white, which increase and wane as they are turned from or toward the sun; inclosed in an atmosphere, in which clouds often obscure the lines beneath; and accompanied by a satellite. This planet is the Earth.

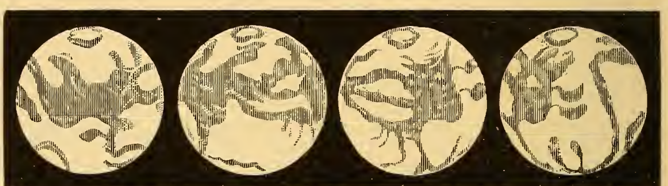
Although the inhabitants long deemed it the central body in the universe, this observer sees that it is neither the largest nor the noblest member of the solar family; a family whose sun itself, the grandest object therein, is but an inferior member of the magnificent group of suns which occupy, each in solitary majesty, a place in that part of the universe within the scope of his vision.

"What is man that thou art mindful of him?"

MARS.

SIGN ♂, A SHIELD AND SPEAR.

418. **Appearance.**—To the naked eye Mars is the reddest star of the sky, shining with a steady brightness, which varies



Telescopic views of Mars; perihelion.

Fig. 137.—Views in aphelion.

with its distance from the earth. In the telescope its color is less intense, and is relieved by spots of bluish green or white. The red portions are thought to be land, showing the general color of rocks and soil; the green tints are believed to come

from water. Definite outlines of lands and seas are discernible. Mr. Dawes has mapped them, and they have received the names of distinguished astronomers, who have given special study to this planet. The long, bottle-shaped seas,

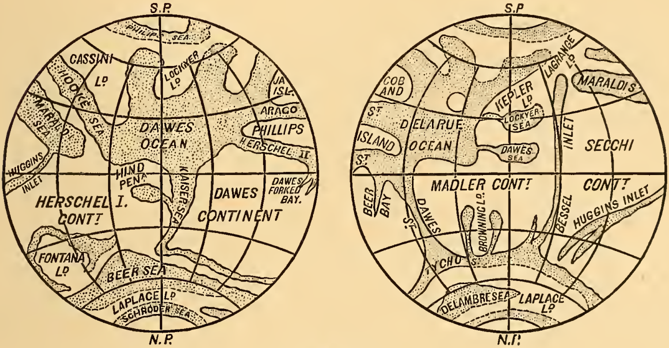


Fig. 138.

and the vast length of coast-line contrast strongly with the broad oceans and compact continents on the earth.

419. Rotation.—The movement of the spots indicates the rotation of the planet in 24 h. 37 m. 22.7 sec. about an axis inclined 63.° to the plane of its orbit. The solar day is 24 h. 39 m. 35 sec.

420. As the axis has an inclination not much different from that of the earth, the seasons must vary in a similar manner (211–224). White spots, brighter than the rest of the disc, appear about the poles; when a pole is turned toward the sun, the spot about it diminishes, while the opposite one increases, and conversely. In 1837, during winter at the south pole of Mars, the whiteness extended 35°; in 1830, in summer at the same pole, the spot reached only 5 or 6 degrees from the pole. These facts lead us to suppose that the whiteness is reflected from snow and ice which gather and melt away as on the earth. Hence, we infer

that Mars has water, an atmosphere, and variations of climate like our own. The varying clearness of outlines, as seen near the center of the disc, or at the edge, also indicates the presence of an atmosphere, while occasionally the whole disc, or a part of it, seems to be obscured by clouds.

421. **Orbit.**—The mean radius of the orbit is about 142 millions of miles, with an eccentricity of about 13 millions, or 0.093. In 1877, Mars came to opposition when near its perihelion, while the earth was near aphelion; the distance between the two bodies was nearly a minimum, about 35 millions of miles. If these conditions are reversed, Mars coming to opposition near its aphelion, when the earth is near its perihelion, the distance between the planets will be about 62 millions of miles. Evidently the first case will be most favorable for observations. The next oppositions will occur in March, 1886, April, 1888, and May, 1890, etc.

The planet moves at a mean rate of about 15 miles a second, and traverses its orbit in a little less than 2 of our years (687 days); during that time it makes 669⅔ rotations, and it has, therefore, 668⅔ solar days in its year.

Its orbit makes with the ecliptic an angle of about 2° (1° 51′).

Its diameter is about 4200 miles. The polar diameter is shorter than the equatorial by an amount not accurately determined.

422. **Satellites.**—At the near approach to the earth, in 1877, Mars was carefully studied by Hall, using the great Washington refractor. On the night of August 11, he discovered, in the vicinity of the planet, a small object, which later examination proved to be a satellite. On the night of the 18th, a second satellite was seen. The newly discovered bodies were named Deimos and Phobos. They are by far the smallest heavenly bodies yet known. Their data are as follows:

Name.	Mean Distance.		Period of Revolution.	Diameter. Miles.
	Mars' Dia.	Miles.		
Phobos	1.39	5820	7 h. 39 m.	5 to 20
Deimos	3.48	14600	30 h. 17.9 m.	10 to 40

Phobos is remarkable because its time of revolution is less than one third the planet's day. It is the only instance known in which the time of revolution of a satellite is less than the time of rotation of its primary.

423. RECAPITULATION OF INNER GROUP.

The four planets, Mercury, Venus, Earth, Mars, form what is called the *inner group*. A comparison of more important items shows many points of similarity, with occasional differences.

In size, Venus and Earth nearly agree; Mercury is a little less, Mars a little more, than half as large.

In inclination of axis, Mars agrees with Earth.

In time of rotation, and consequent *length of day*, so far as known, all show a remarkable coincidence.

Venus, Earth, and Mars have each an *atmosphere*, hence *twilight;* all shine by *reflected light*, hence show *phases*.

Mars is probably diversified by *seas* and *continents* like Earth.

Earth has *one satellite;* Mars has *two*.

	Mercury.	Venus.	Earth.	Mars.
Diameter in miles,	3000	7700	7913	4200
Inclin. of axis,			66½°	63°
Solar day,		23 h. 27½ m.(?)	24 h.	24 h. 39½ m.
Mean distance from Sun, in millions of m.	36	67	93	142
Velocity in orbit, m.	29.6	21.6	18.4	15.

CHAPTER XVII.

THE MINOR PLANETS.

424. The space between Mars and Jupiter. — As soon as the planetary distances were determined, astronomers saw that as far as to the orbit of Mars, distances increase in a somewhat regular order; that between Mars and Jupiter, a wide gap destroys the symmetry otherwise apparent. Kepler suggested that a new planet might be found in this space.

425. The series of Titius. — Titius of Wittenberg sought for a simple series of numbers, which should represent the relative distances of the planets from the sun. After many trials, he took the series,

0, 3, 6, 12, 24, 48, 96, etc.,

in which each term after the second is twice the preceding term; adding 4 to each, he found numbers which indicate very nearly the relative distances, as shown in the following table, as the planets are now known.

At the time when this series was observed, the Minor Planets, Uranus, and Neptune were not known.

When Herschel discovered the planet Uranus, its distance was found to correspond with its number in the series, but a planet was still wanting whose distance should answer to the number 28. This vacancy has been found to be filled in a way not expected, as we shall describe.

Planets.	Series of Titius.	Actual Distances.	
		Millions.	Earth = 10
Mercury,	0 + 4 = 4	36	3.9
Venus,	3 + 4 = 7	67	7.1
Earth,	6 + 4 = 10	93	10.
Mars,	12 + 4 = 16	142	15.2
Minor Planets,	24 + 4 = 28	250	27.
Jupiter,	48 + 4 = 52	483	52.
Saturn,	96 + 4 = 100	886	95.
Uranus,	192 + 4 = 196	1780	192.
Neptune,	384 + 4 = 388	2790	300.

Following the series, Neptune's number should be 388; but his distance is 2790 and his number 300. Here the series fails. Instead of showing a law, it shows probably only a remarkable coincidence.

426. **Discovery of Ceres.**—In 1800 an association of astronomers determined to conduct a systematic search for a planet between Mars and Jupiter. January 1, 1801, Piazzi, at Palermo, saw a new star, which he at first thought was a comet; it proved to be a planet, and its orbit was found to occupy the place in question. To this planet he gave the name Ceres. But the symmetry of the system, which seemed to have been so fully established, was again disturbed during the next year by the discovery of another small planet at nearly the same distance; in a few years, two more were found.

427. **Farther discoveries.**—In 1845 a fifth was discovered, and since then others have been added rapidly to the list, until at present (March, 1884,) about 220 have been found, and their orbits determined. They have been called *Asteroids* (star-like), *Planetoids* (planet-like), or Minor Planets.

All move in elliptical orbits, in obedience to Kepler's three great laws.

428. Their peculiar characteristics.—

1. They can be seen only with the telescope, and even then are known to be planets only by their motion. The figure shows a portion of the sky as seen in the field of a telescope, crossed by the illuminated wires of the reticule (80); the

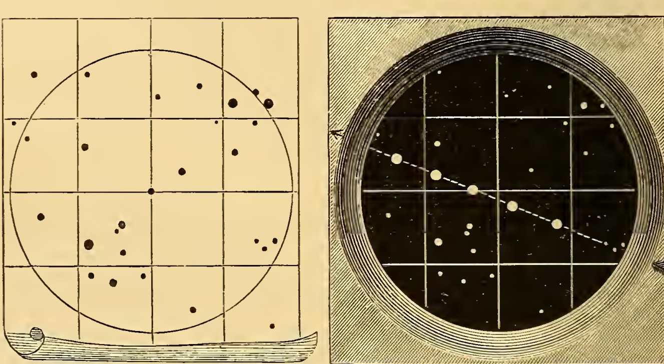


Fig. 139.

known stars are mapped on a corresponding chart, and the new planet is recognized by its motion across the field.

Because so small, they are measured with the greatest difficulty. The largest is supposed to be not more than 300 miles in diameter, with a surface not larger than that of some islands on the earth. Newcomb estimates that the combined volume of all which have been found would make a planet not exceeding 400 miles in diameter.

2. Their orbits are very eccentric, and much inclined to the plane of the ecliptic.

3. Their orbits are included in a broad ring, at a mean distance from the sun of 250 millions of miles. Most of them at perihelion come nearer the sun than the nearest at its aphelion. The orbits are so interlaced that, if they were material rings or hoops, one could not be lifted out of its place without taking all the others with it.

429. **Origin of the Minor Planets.**—Dr. Olbers suggested that they are the fragments of a large planet shattered by an explosion. As the pieces of a shell, after bursting, retain the forward motion of the shell while they diverge from each other, so the fragments of an exploded planet must continue to revolve about the sun, their orbits being modified by the force of the explosion.

To Olbers' theory it is objected that all the orbits which the several parts might assume would necessarily meet at the point in space where the explosion occurred, each fragment returning to that point at regular intervals. But no common point is found. In fact, the path of the nearest is never within 50 millions of miles of the orbit of the farthest. Yet such a point may have existed, and the attractions of these planets upon each other, and of the planets on either side, may have so changed their orbits as to cause them to diverge, and to cease passing through this common point.

430. **The Nebular Theory** (Chap. XXIII) supposes that each of the planets was formed originally by the gathering of matter collected by gravitation; that, while the matter in the case of Jupiter or Mars concentrated about one nucleus, that which formed the minor planets gathered about many centers, the several masses being formed about the same time, and at nearly the same distance from the sun; that these numerous small bodies take the place of the one large body which might have been formed had all been compacted into one. Thus the symmetry of the system is preserved even in its variety.

431. **Names and Symbols.**—The discoverers of minor planets assigned names of goddesses from the ancient mythologies, but the list has already grown too long to be easily remembered. It is deemed better to indicate each by a small circle, inclosing a number in the order of discovery; thus, Ceres is (1); Maximiliana, or Cybele, (65); Feronia, (71). There is, perhaps, no limit to the number

which may yet be found, except that many may be too small to be picked up by even the best telescopes. Meanwhile the number now known is so great that it is difficult to follow their motions. It has been suggested that most of those which have been caught may be turned loose again with no loss to the science of astronomy.

432. RECAPITULATION.

Search was made at the beginning of this century for a planet between Mars and Jupiter, indicated by the law of Titius.

Instead of one, *four* were soon found; since 1845, about 200 have been discovered; all are *small*, visible only by the telescope.

Their orbits are *eccentric*, *interlaced*, and make *large angles* with the plane of the ecliptic.

They are not believed to be fragments of a larger planet.

CHAPTER XVIII.

THE OUTER GROUP.—*JUPITER.*

SIGN ♃, FROM THE INITIAL OF ZEUS, THE GREEK NAME OF JUPITER.

433. **Appearance.**—Jupiter is known by his clear, steady light, surpassing in splendor the brightest stars in the sky. In the telescope he shows a beautiful orb, crossed by light

Fig. 140.

and dark bands, and accompanied by four lesser bodies, or moons. Galileo's discovery of the moons of Jupiter, in 1610, was one of the first fruits of the telescope, and was of great value in establishing the truth of the Copernican system. At opposition they may be seen even with a good opera-glass.

Jupiter will be in opposition February 20, 1885; March 20, 1886; April 22, 1887; May 25, 1888; about 33 days later each year than in the year preceding.

434. **The belts.**—When examined with a telescope of moderate power, the disc seems to be crossed by broad grayish

belts, one on either side of the equator, while between them a brighter space, often distinctly rose-colored, marks the equatorial regions. Under higher magnification these belts resolve themselves into streaks and cloud-like masses of very

Fig. 141.

varied forms, so constantly changing that the views of two successive nights are seldom alike. Amid these belts, spots appear, sometimes bright, sometimes dark. These move, but with some degree of irregularity, leading us to think that their motion is partly their own, partly that of the planet. In 1834, Airy followed the same spot for about six months, and, from its motions, determined the planet's rotation in 9 h. 55 m. 21.3 sec. Other observers differ; and still others find that the spots near the equator have a slower motion than those farther away.

435. Resemblances to the sun.—1. The central parts of the disc are brighter than the margin. A satellite, making its transit before the disc, appears bright against a dark background, when near the margin, but dark against a brighter background when near the center. The center is two or three times as bright as the limb.

2. The light of Jupiter is thought to be brighter than it would be if it simply reflected light from the sun. In other words, this planet is suspected of shining partly by its own light.

3. The rapid changes of its belts indicate a great activity, which would suggest great heat; greater than that which could be received from the sun at that distance.

The careful study which has been given to this body with the help of modern instruments, leads to the belief that it has not yet reached the condition which has a cold and stable surface, like that of the earth, but that it is now at a high temperature, perhaps liquid, possibly gaseous, but covered with dense clouds, which may be more or less self-luminous, as they rise from the hot interior.

436. Dimensions and shape.—The mean diameter is nearly 11 times that of the earth (284); 85,700 miles.

If the spheroidal form of the earth is due to its rotation, Jupiter should be flattened still more, because of the more rapid motion at its equator, caused both by greater size and by quicker rotation. It is possible to compute, from the laws of gravity and of motion, what this flattening should be, and observation shows that the theoretical results correspond with actual dimensions. The polar diameter is shortened about one seventeenth.

437. Moons.—The four moons are named in their order from the planet: Io, Europa, Ganymede, Callisto. In order of size they are, third, fourth, first, second; Ganymede is 3700 miles in diameter,—a little smaller than Mars; Europa, the smallest, 2200,—a little larger than our moon. In the

Jovian sky, the disc of the first appears about as broad as our moon appears to us; the others are less. They revolve about Jupiter in elliptical orbits, in conformity with Kepler's laws.

Name.	Mean Distance.		Period of Revolution.	Diameter. Miles.
	Planet's Dia.	Miles.		
Io,	6.05	259,000	1.77 days.	2,500
Europa,	9.62	412,000	3.55	2,200
Ganymede,	15.35	658,000	7.15	3,700
Callisto,	26.99	1,156,000	16.69	3,200

438. Their eclipses.—Their orbits are inclined to the orbit of Jupiter but slightly, while Jupiter's orbit makes an angle of less than 2° with the plane of the ecliptic. Hence, each moon at each revolution is likely to pass into the shadow of the planet, and be *eclipsed;* to pass behind the planet, and be *occulted;* or to pass between us and the planet, making a *transit.* It may also pass between the planet and the sun, causing at Jupiter a solar eclipse, and showing to us a black shadow crossing the disc. In Fig. 142 the first moon is eclipsed; the second makes a transit as seen from the earth, while its shadow makes an eclipse of the sun at a place on the planet; the third is in occultation, and is not visible from the earth. Reference has already been made to these eclipses as valuable for determining terrestrial longitude (113).

439. Orbit of Jupiter.—A complete revolution is made in about 12 years (4332.6 days). From this (274), his mean distance is found to be 483 millions of miles. The eccentricity is about 23 millions of miles, or 0.0483. The plane of the orbit makes, with that of the ecliptic, an angle of little more than 1° (1° 18′ 41″). The planet moves at a rate of about 8 miles a second.

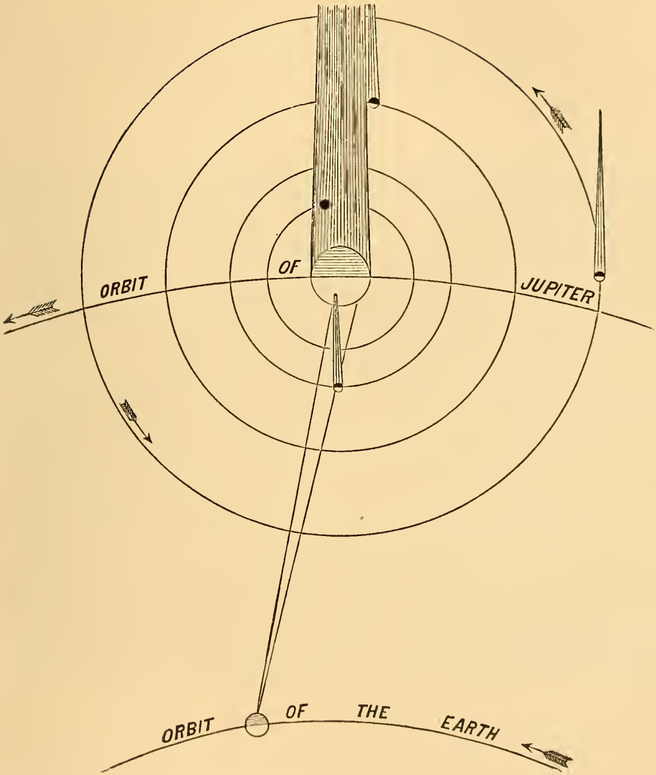


Fig. 142.

SATURN.

SIGN ♄, A RUDE SCYTHE, OR SICKLE.

440. Appearance.—Saturn shines with a steady silvery light, like a star of the first magnitude, but without twinkling. In the telescope it presents a most magnificent display, revealing a system of satellites and a splendor of rings which surpass the glory of the entire solar system as known to

Ptolemy. The times most favorable for observation will be about December 24, 1885; January 6, 1886; January 19, 1887, etc.; each year about 13 days later than on the year preceding.

The disc, like that of Jupiter, is crossed by streaks or belts, which are less distinctly seen because of greater distance. In 1876, a notable white spot appeared near the equator, and, from its movements, Hall found the time of the planet's rotation to be 10 h. 14 m., a time a little less than that previously given by W. Herschel.

The inclination of the axis to the plane of its orbit has been given at about 63°. As might be expected from the rate of rotation, the sphere is flattened; its polar diameter is shortened about one tenth (Bessel), or one ninth (Hind).

The mean diameter of the planet is about 70,000 miles.

THE RINGS OF SATURN.

441. **Galileo's discovery.**—To Galileo, in 1610, the planet showed an oval disc, or a central body with two semilunar wings. Hence, he supposed it to be a triple body, a large planet with two constant attendants. Two years later, he again examined the planet, but the attendants had vanished. This fact, now well understood, gave him much anxiety, and led him to fear that he might have been deceived in other discoveries. "Can it be possible," said he, "that some demon has mocked me?"

442. **Huyghens' discoveries.** — In 1655, Huyghens saw, in a more powerful telescope, that Saturn is surrounded by a broad, thin ring, nearly parallel to the planet's equator, and inclined to the ecliptic about 28°. The plane of the ring, like the axis of the earth (217), is always parallel to itself; in certain relative positions of Saturn and the earth, one side of the ring is visible; in others, the opposite side; in going from one to the other, the earth passes a point where

only the edge of the ring can be seen, invisible in telescopes of lower power, and in larger instruments appearing as an extremely fine, bright line. It was this vanishing of the ring which puzzled Galileo.

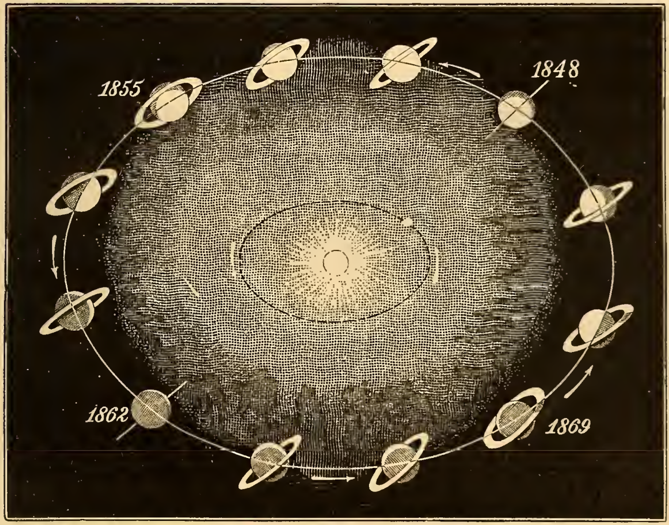


Fig. 143.

In 1665, two English observers, named Ball, perceived the dark streak which separates the ring into two principal parts. It is said that stars have been seen through this dark streak, showing that the space is devoid of solid matter. Other streaks have been seen at various times, but none remain permanently visible; were all verified, there would be at least five concentric bright rings.

443. **Bond's discovery.**—In 1850, Bond saw, within the bright rings before known, a ring of faint gray light, so transparent that the planet is visible through it. At first, it was thought that some important change had occurred, but records of former observations show that it had been seen

before, and mistaken for a belt on the surface of the planet; on the other hand, it appears that when discovered it was an object not easily observed, and that now it may be seen in a telescope of moderate power.

Mr. Bond first recognized its true character; very soon Otto Struve and Dawes perceived and measured a dark line in this ring.

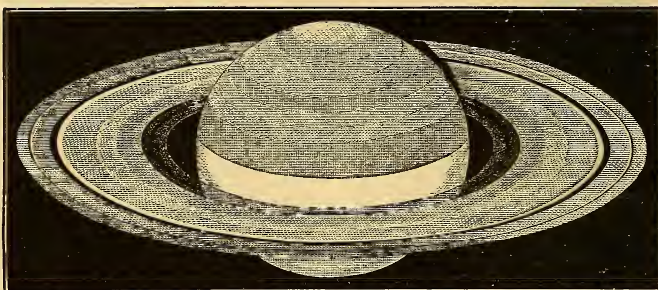


Fig. 144.

444. **Dimensions of the rings.**—The equatorial diameter of Saturn is about 74,000 miles. The dimensions of the rings, giving the mean results of Struve and De la Rue, are nearly as follows, measured from the planet's center:

Equatorial radius of planet, miles,		37,000
Space to dark ring,	8,000	45,000
Space to bright ring,	18,000	55,000
Breadth of inner bright ring,	16,500	71,500
Space between rings,	1,500	73,000
Breadth of outer ring,	10,000	83,000
Diameter of outer ring,		166,000

The thickness is variously estimated at from 40 to 250 miles. When the edge only is visible, it shows in the telescope a bright line, so delicate that the fine spider-line in the

focus of the instrument seems a cable by comparison. At the same time the satellites which revolve in nearly the same plane are seen moving along this line of light, "like pearls strung on a silver thread."

The rings revolve in their own plane about the center of the planet in 10 h. 32 m.

445. **What are the rings?**—Their brightness and the shadows which they cast upon the planet indicate that they consist of solid, or at least of opaque, material. The dark lines which streak them, showing either constant or only occasional separation into distinct bands, indicate that the solid particles do not cohere. Pierce demonstrated that they are not solid, and Clerk Maxwell that they are not liquid; the appearance of the dark ring and an apparent increase in breadth of the whole system since the days of Huyghens, of some 29 miles a year, corroborate this opinion.

Our moon is kept in its place by the combined forces of gravitation and revolution in its orbit. A second moon following in its path would be supported in the same way. We may conceive of a procession of moons following each other in immediate succession, each moon, and, in fact, each particle in each moon, whether adhering to another particle or not, sustained independently of all the other members of the procession. So each particle in the rings of Saturn is a satellite revolving about its primary in obedience to the laws of planetary motion.

To complete the hypothesis, it is supposed that the dark inner ring consists of comparatively few particles which have been removed from the denser crowd of the bright rings by the irregular attraction of the satellites in their revolutions; while the general increase in width, if a fact, is explained in the same way.

446. **Experiment.**—Invert a large glass receiver, with swelled sides, such as is used with an air-pump, and suspend

it by a triple cord to a hook in the ceiling. Pour a few ounces of mercury into the receiver, and twist up the cord; when the glass is set free, the untwisting cord causes rapid rotation, and the mercury, obeying the tangential force, flashes into the swell and revolves there in a continuous ring. A few shot, or marbles, illustrate a ring of non-coherent solid particles.

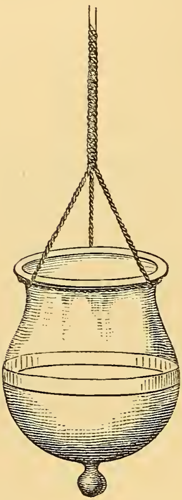


Fig. 145.

A glass jar upon a whirling-table shows the same results.

447. **Satellites.** — Besides the system of rings, Saturn has eight moons. Their names in order, beginning with the nearest, are Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Japetus. Titan is the largest, with a diameter of 3,000 miles; the diameters of the others are approximately as given in the table. The orbit of the outer is inclined 12° 14′ to the plane of the rings; the others nearly coincide with it.

Name.	Mean Distance.		Period. Days.	Diameter. Miles.
	Rad. of ♄.	Miles.		
Mimas,	3.4	115,000	0.94	1,000
Enceladus,	4.3	150,000	1.37	?
Tethys,	5.3	185,000	1.88	500
Dione,	6.8	238,000	2.73	500
Rhea,	9.6	332,000	4.51	1,200
Titan,	22.2	770,000	15.94	3,200
Hyperion,	26.8	988,000	21.29	?
Japetus,	64.4	2,254,000	79.33	1,800

448. **Orbit.**—A complete revolution of Saturn occupies about 30 years (10,759.2 days). The mean radius vector

is 886 millions of miles; the eccentricity being about 50 millions, or 0.056. The angle with the ecliptic is about $2\frac{1}{2}°$ ($2° 29' 39''$). The rate of motion in its orbit averages rather less than 6 miles a second.

URANUS.

SIGN ♅, THE INITIAL OF HERSCHEL, WITH A GLOBE SUSPENDED FROM THE CROSS-BAR.

449. **Discovery.**—In 1781, Sir William Herschel, while examining the small stars within the sweep of his telescope, saw one which showed a well-defined disc; continued observation detected a change of place. The new body was thought to be a comet. Farther observation and the computation of its orbit, proved it to be a great planet, before unknown. Herschel proposed to name the stranger the Georgium Sidus, in honor of the reigning king of England. La Place proposed to call it Herschel, for its discoverer. It finally received the name of *Uranus*, who, in the ancient mythology, was the father of Saturn.

By tracing back the path of the planet, records were found of more than twenty observations, made during the ninety years previous to the discovery of Herschel, but the observers had thought it a fixed star. Lemonnier had observed it no less than twelve times, and missed the honor of its discovery by his want of method in recording his observations.

450. **Appearance.** — When nearest the earth Uranus appears like a star of the sixth magnitude, and *may* be seen without a telescope. It will be in opposition about March 23, 1885, and each year about $4\frac{1}{2}$ days later than in the year preceding. The disc is too small to be measured easily. The diameter is believed to be about 32,000 miles. Mädler found a flattening of $\frac{1}{10}$; but other observers are unable to

verify it. The axis may lie near the plane of the ecliptic; the body would then seem to be circular while the pole is turned toward the earth, and would show oblateness only

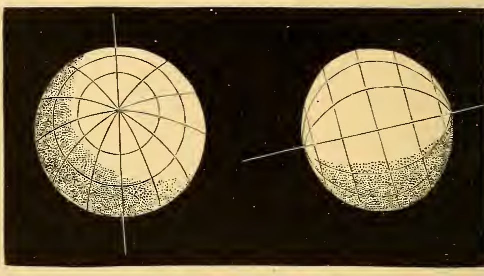


Fig. 146.

when both ends of the axis are visible. The position of the orbits of the satellites lends probability to this suggestion.

The flattened shape indicates rotation, but no time of rotation has been determined.

451. **Satellites.** — Herschel reported six and Lassell added two others. Only two of Herschel's have been verified, and it is now believed that but four exist. They are named Ariel, Umbriel, Titania, and Oberon. Unlike any planets or satellites before known, they have a *retrograde* motion almost at right angles to the plane of the planet's path. Instead of calling the motion retrograde at an angle of 79°, it may be considered direct at an angle of 101°.

Name.	Mean Distance.		Period. Days.	Diameter. Miles.
	Rad. of ♅.	Miles.		
Ariel,	7.44	119,000	2.52	?
Umbriel,	10.37	166,000	4.14	?
Titania,	17.01	272,000	8.71	?
Oberon,	22.75	364,000	13.46	?

452. Orbit.—The sidereal revolution occupies about 84 years (30,686.8 days). Its mean distance is about 1780 millions of miles, the eccentricity being .046. The angle of the orbit with the plane of the ecliptic is about ¾ of a degree (46′ 21″). The rate of motion is about 4.2 miles a second.

NEPTUNE.

SIGN ♆, A TRIDENT.

453. Disturbing influences of planets upon each other.—A planet influenced by no other attraction than that of the sun, would describe an exact ellipse with one focus at the sun. But no planet is so situated; in every case the path is modified in some degree by the attractions of other bodies in the system. As the places and masses of the bodies are known, their influences on each other are calculated; and from these data, tables have been computed, predicting the places of each for many years. Bouvard constructed such tables for Uranus, but the planet did not answer the predictions. Its motions led astronomers to look beyond its orbit for some large unknown body, whose attraction would account for the irregularities observed.

454. Discovery of Neptune.—The solution of the problem, known to be very difficult, and by many deemed impossible, was undertaken in 1843 by Adams of Cambridge, England, and not long after by Leverrier of Paris, each being ignorant of the purpose of the other. The results thus independently obtained agreed within 1°. Adams sent his to the Astronomer Royal at Greenwich, in October, 1845, but observations were not made before July of the next year, and did not then effect a discovery. On the 31st of August, 1846, Leverrier published his results and sent them to the observatories in Europe. On the 23d of September, the

very day on which the information was received, Gallé, at Berlin, having also received a new and accurate map of the quarter of the heavens indicated, turned his telescope thither, and found the predicted planet within 52′ of the place which Leverrier had assigned. The predicted diameter was 3.3″, the observed 3″.

455. **The discovery perfected.**—The new planet was soon found to be following an orbit somewhat different from that predicted by Adams and Leverrier. An exact determination of its path from observation required data extending over many years. Search was made by European astronomers to see if it, like Uranus, had not been at some time mistaken for a fixed star, but without success.

Mr. Sears C. Walker, of Philadelphia, computed, from the few observations taken, a new orbit, and by tracing this back, found that the planet had been twice observed in 1795, by Lalande, who recorded it as a fixed star. Lalande, being afterward unable to find the star in the same place, had marked his previous observations as doubtful, and Walker found its place vacant. But the new orbit accorded with the observations of Lalande, and of 1846, while the motion of the planet along this path accounted for all the perturbations of Uranus during that period.

Thus the orbit and the observations mutually verify each other, while to an American belongs the honor of perfecting the discovery of this remotest known member of our solar system,—the most remarkable triumph of mathematical astronomy.

456. **The planet.**—In the telescope, Neptune has the aspect of a star of the eighth magnitude. Its diameter is about 35,000 miles. No spot, or flattening of shape, has been observed; hence, nothing is known of its rotation. Its time of revolution is about 165 years (60,126.7 days). The orbit has a mean radius of 2790 millions of miles, with an eccentricity of 0.0089, and is inclined to the ecliptic

about 1¾° (1° 46′ 59″). Its rate of motion is about 3½ miles a second.

As before remarked (425), Neptune's distance from the sun does not conform to the Series of Titius, which by this fact is recognized only as a notable coincidence.

457. Satellite.—Only one moon is known, although the existence of another has been suspected. The known satellite revolves in 5 d. 21 h., at a distance of 210,000 miles. Its motion is retrograde, in an orbit nearly circular, inclined 34° 53′ to the orbit of the planet. From this moon, the mass of the primary is found (293), and from the mass its density, which is little more than that of water.

ASTRONOMICAL APPARATUS.

458. Diagrams and Orreries.—The inadequacy of diagrams, or of machines, to represent the distances and motions of the planets is strikingly shown in the following quotation from Herschel's Outlines of Astronomy:

"Choose any well leveled field or bowling-green. On it place a globe, two feet in diameter; this will represent the sun; Mercury will be represented by a grain of mustard-seed, on the circumference of a circle 164 feet in diameter, for its orbit; Venus, a pea, on a circle 284 feet in diameter; the Earth, also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; the Minor Planets, grains of sand, on circles of from 1000 to 1200 feet; Jupiter, a moderate sized orange, on a circle nearly half a mile across; Saturn, a small orange, on a circle four fifths of a mile; Uranus, a full sized cherry, upon the circumference of more than a mile and a half; and Neptune, a good sized plum, on a circle about two miles and a half in diameter.

"As to getting correct notions of this subject by drawing circles on paper, or, still worse, from those very childish toys,

called orreries, it is out of the question. To imitate the motions of the planets, in the above-mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus, in 4 m. 14 s.; the Earth, in 7 m.; Mars, in 4 m. 48 s.; Jupiter, in 2 h. 56 m.; Saturn, in 3 h. 13 m.; Uranus, in 2 h. 16 m.; and Neptune, in 3 h. 30 m."

459. RECAPITULATION OF OUTER GROUP.

The four planets, Jupiter, Saturn, Uranus, and Neptune, form what may be called the *outer group* of planets. In certain respects they are like each other, and unlike the planets of the inner group.

In size, Uranus and Neptune have about 4, Saturn, 10, and Jupiter, 11, times the diameter of the earth.

The time of rotation of Jupiter and Saturn, about 10 hours, is notable for its shortness, especially when size is considered, and when compared with the 24 hours of the inner planets.

In density, each is not greatly different from *water;* Jupiter and Uranus are each about one fourth more, while Saturn is about as much less.

All are attended by *satellites;* those of Uranus and Neptune are notable for moving from *east* to *west*, unlike any other bodies in the system.

	Jupiter.	Saturn.	Uranus.	Neptune.
Size,	86,000	70,000	32,000	35,000
Solar day,	9 h. 55 m.	10 h. 14 m.		
Density,	1.4	0.75	1.28	1.15
Satellites,	4	8	4	1
Distance from sun In millions of m.	483	886	1780	2790
Velocity in orbit, m.	8.06	5.95	4.20	3.36

CHAPTER XIX.

COMETS.

460. The name.—The ancients gave the name *comet** to those brilliant objects which appear, suddenly and for a brief period, in the sky, and are usually attended by long flaming trains. The telescope shows that they consist mainly of misty, nebulous substance, and it reveals many similar bodies not attended by luminous trains. However irregular their apparent motions, they move in well-known curves, and always about the sun as their common center of attraction.

461. Numbers.—The Chinese have recorded the advent of comets since about 600 years before the Christian Era. Including those records, the lists of comets for the last 2500 years mention between 700 and 800. But, in early ages, only the most remarkable were noted; while of the many seen during the last two centuries, most have been visible only with the telescope. Doubtless a like proportion passed previously without record.

Very many comets were not formerly seen, and are not now, because they appear above our horizon only in the daytime; a large comet was once revealed by an eclipse of the sun. The number, therefore, of comets which have passed the earth during the historic period must be several thousand. If this number be increased by those which had

* Κομήτης, *kometes*, wearing long hair.

previously visited our sky, and by the multitudes now on the way to blaze in our heavens during the centuries to come; and be farther augmented by the myriads more which doubtless enter our system, but pass the sun too far away to be seen at the earth; we may readily conclude, with Arago, that the comets belonging to the solar system are numbered by millions, and with Kepler, that they are countless, "as the fishes in the sea."

PARTS OF A COMET.

462. **The bright point** near the center of the principal mass of a comet is called the *nucleus;* the light haze about the nuclues is the *coma;* the two together form the *head.* The luminous trail is the *tail.* Often the tail is absent,

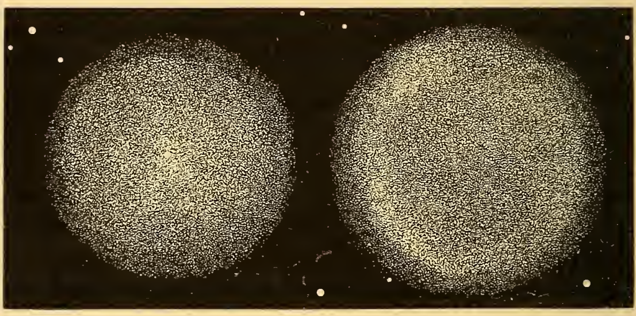


Fig. 147.—Comet without tail. Comet without nucleus.

especially from the smaller comets, and occasionally no nucleus is found; the comet being merely a globular mass of coma. The stream of light which forms the tail, appears to issue from the head toward the sun, and then, as if blown away by some repulsion in that body, it is folded back about the nucleus, and swept far out into space.

463. **Comets are material.**—This is evident, since they obey the laws of gravitation. They move about the sun in

regular orbits; their returns have been successfully predicted; and they are influenced by the attraction of planets in whose vicinity they pass.

But this material substance is exceedingly rare. Small stars have been distinctly seen through the densest part of a comet, where its diameter was 50,000 to 100,000 miles; the same stars would be completely obscured by the rarest fog, or the lightest cloud. Evidence of more value to the astronomer is the fact that large comets have passed near planets and satellites without causing the least perceptible disturbance in the motions of those masses.

The spectroscope indicates that the nucleus of a comet is self-luminous at a high temperature; and that the substance about the nucleus contains a compound of hydrogen and carbon.

The spectroscope, and in a measure the polariscope indicate that the light from comets is also in some degree reflected from the sun.

464. **Apparent dimensions.**—The comets of 1618 and 1861 covered more than 100° in the sky; the tail might have passed the zenith, while the head was still below the horizon. The length of the comet of 1680 was variously stated at from 70° to 90°; that of the comet of 1843 was estimated at about 65°. The light of the tail often fades so gradually that it is very difficult to tell where it ends. This wonderful appendage, that streams across the sky like a flaming sword, has made the appearance of a great comet an occasion of terror during most ages of the world.

465. **Variations.**—Some of the brightest comets have had short and feeble tails, and some great comets have had none. Cassini mentions two whose discs were as round and as distinct as Jupiter.

A small comet in 1823 had two distinct tails, the brighter being turned from the sun, while a smaller one nearly opposite was turned toward the sun.

The tail of the comet of 1744 was divided into many branches, as if there were several distinct tails.

466. Actual dimensions.—The apparent size of a comet does not always indicate its actual length; a long tail would appear short to an observer in certain positions.

Fig. 148.—Comet of 1744.

The actual diameter of the nucleus, when any is seen, is estimated at from 25 to 800 miles, rarely more than 500. The coma has sometimes a diameter of 200,000 to 350,000 miles; that of the comet of 1811 was 1,125,000 miles. The tail of the same comet was more than 100 millions of miles long; that of the comet of 1680, when largest, was nearly 125 millions of miles in length,—one third longer than the distance from the earth to the sun.

THE TAIL.

467. The development of the tail.—When a comet is first seen, it has usually little or no tail; as it approaches the sun, the coma expands, and the tail grows longer and brighter. While passing the sun, it sometimes expands with a rapidity almost inconceivable. The tail of the comet of 1858 grew two millions of miles daily; that of 1811, nine millions; and that of 1843 expanded *seventy* millions of miles in *two days*. After the comet has passed the sun, the tail diminishes again, and has often nearly vanished before the head disappears.

468. The cause of the tail.—Its position, always turned from the sun, its increase when approaching that body, its decrease when retiring, all indicate that it is produced by some unknown repulsive power in the sun, unlike gravitation, and opposed to it. The supposition that the comet carries its tail along with it involves consequences that could not exist. Stretching so far away as the dimensions sometimes found, if the tail were swinging around like the spoke of a wheel, the outer parts must be moving at such a rate as would overcome all radial force, and send the separated fragments far out into space. Newcomb suggests that the tail is a stream of vapor emanating from the comet like smoke from a chimney, constantly floating away, and constantly renewed.

469. The curvature of the tail gives a hint of the way in which it is formed, though not of the force. Suppose the nucleus moves along the curve *ABC*, about the sun. When at *A*, the unknown power in the sun drives a particle of matter from the coma, with a force which can carry it to *D*, while the nucleus moves to *C*; the particle, obedient to this repulsion, and to the forward motion which it had on *AC*, is found at *E*, as far forward of the line *AD* as the

distance through which the head has moved; it is not in the line *SCL*, passing through the sun and the nucleus.

While the head is at *B*, half way from *A* to *C*, another particle is repelled, which in like manner may be traced to

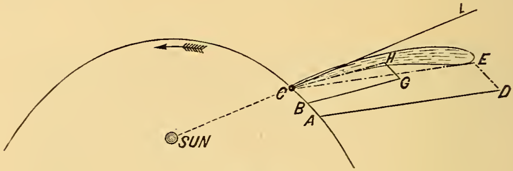


Fig. 149.

the point *H*. This point is also behind the line *SL*, but not half as much as the point *E*, because *BG*, the line of the second repulsive action, is not parallel to *AD*, the line of the first. Similarly, all the particles in the tail find their places, and the tail is always convex toward the direction in which the comet moves.

470. The tail hollow.—It is usually remarked that the edges of the tail are brighter than the portion between; there

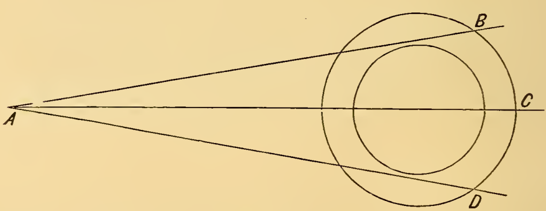


Fig. 150.

seem to be two streams of light connected by a fainter web. This indicates that the tail is hollow,—a constantly expanding tube. Its cross section is a ring, either circular or oval, as in the figure; more luminous matter lies in the lines of *AB* and *AD* than in *AC*.

THE HEAD.

471. **Variations of the head.**—When the comet comes near the sun, both nucleus and coma often diminish, to increase again as the body recedes. It has been suggested that the intense heat may expand the substance of the comet into transparent, invisible vapor; when the heat diminishes, this vapor, like steam, may become visible again in cooling. As the diminution of the head occurs at the same time as the expansion of the tail, one fact may explain the other; the substance being repelled to form the tail.

472. **Is the nucleus solid?**—Herschel saw a star of the twentieth magnitude, through the brightest part of a comet. Messier, while observing a comet, saw, after a time, a small star near, which he thought the comet had concealed, as he had not noticed it before, but he did not see either the beginning or the end of the occultation.

The fact that comets show no phases, is important but not conclusive, as they may shine, in part at least, by their own light. Arago proved by the polariscope that a portion of the light is reflected from the sun. This may be the fact, and the comet be self-luminous also.

THE ORBITS OF COMETS.

473. **The cone.**—When a line, *AB* (Fig. 151), revolves about another line, *CD*, which it crosses obliquely at *V*, it produces two surfaces, each of which we ordinarily consider the surface of a cone; but as both surfaces are generated at once by the revolution of one line, they are deemed two parts or *sheets* of the same conical surface.

CD is its *axis*. The line *AB* in any position, as *A′B′*, is an *element* of the cone.

474. The conic sections.—Through any point, *P*, in either sheet of the cone, pass a plane perpendicular to the axis; the intersection is a *circle*, *PE*, being its diameter.

Keeping the point *P* fixed, turn the cutting plane, making it intersect the opposite element either above or below *E*, as at *R;* the section is an ellipse, and *PR* is its *major axis*.

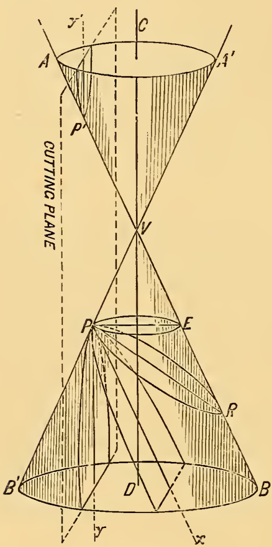


Fig. 151.

A circle is one variety of the ellipse (188).

Turn the plane until it is parallel to the opposite element of the cone; the section is now a *parabola*. Evidently the two branches of the parabola can never meet each other or the opposite element of the cone. It is an ellipse whose major axis, *Px*, is infinite.

Turn the plane yet farther. It now cuts the opposite sheet of the cone; the section is a *hyperbola*. Its branches can never meet, but may go on infinitely, becoming more and more nearly straight lines.

These three curves, the ellipse, the parabola, and the hyperbola, with their possible varieties, are known as the *conic sections*. They have each at least one *vertex*, which answers to the point *P;* a *major axis*, which passes through the vertex, and either meets, or is parallel to, the axis, *CD*, of the cone; and at least one *focus*.

475. The general law of celestial motion.—Newton demonstrated mathematically that a body must move in the curve of some one of the conic sections, if impelled by two

forces, one of which is a constant central force, as the attraction of gravitation; and the other, a tangential or impulsive force. This led him to believe that comets obey the same laws which govern planets.

The great comet of 1680 furnished an opportunity for testing this deduction. From a large number of observa-

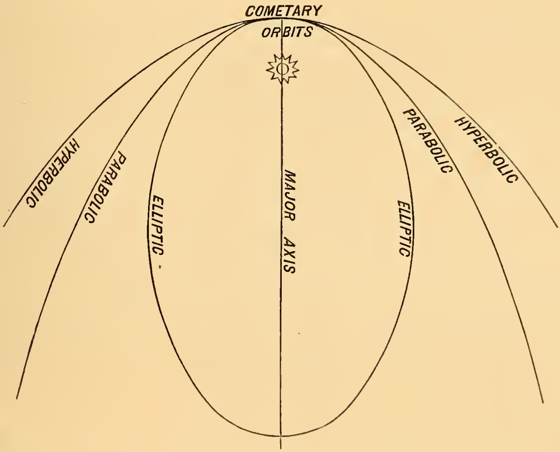


Fig. 152.

tions, Newton found that its path was the curve of a parabola, or of an ellipse so eccentric, and with a major axis so long, as not to be distinguished from a parabola; that the sun was at the focus; and that the radius vector described equal areas in equal times.

476. The elements of a cometary orbit.—The orbit lies in a plane which passes through the sun's center, and which may have any degree of obliquity to the ecliptic. The terms *perihelion*, *aphelion*, *ascending node*, and *descending node* have the same meaning as in the orbits of the planets.

Let S be the sun; $CERE'$, the ecliptic; and the inner curve, part of a cometary orbit. The curve EPE' is the apparent path of the comet on the sky, as seen *from the*

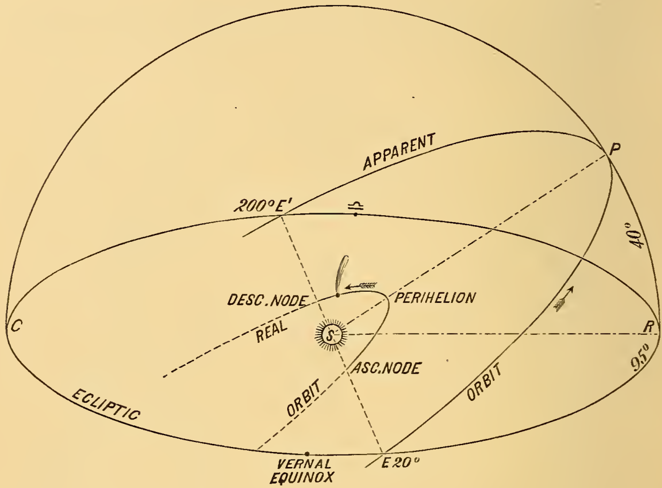


Fig. 153.

sun, or as it would be traced on a celestial globe. To determine the orbit we find:

1. **The inclination,** or the angle which the plane of orbit makes with the plane of the ecliptic. It is the angle PSR, or the angle which the two curves make at E, the ascending node being always taken for the sake of uniformity.

2. **The position of the axis.**—The axis passes through the focus, which is at S, and the vertex, which is at the perihelion. The apparent place of perihelion, on the sky, is at P. Suppose a circle drawn through P, perpendicular to the ecliptic, and meeting it at R; the longitude of R shows the position of the axis; it is called the *longitude of the perihelion.*

3. **The position of the nodes.**—The line of nodes, *ESE'*, passes through the sun; we have only to find the longitude of the ascending node; the other node is distant 180°.

4. **The perihelion distance**, which is the distance in miles of the perihelion from the center of the sun.

5. **The eccentricity.**

6. **The motion** is either direct, as in Fig. 153, or retrograde.

In the diagram, the angle of inclination is 40°; the longitude of perihelion, 95°; the longitude of the ascending node, 20°.

477. How may we know a comet on its reappearance?—Not by its form. Since a comet changes so much during a single passage about the sun, we can hardly expect that the second series of changes should be like the first. It is very improbable that two comets would follow each other in the same orbit. If, then, the orbit of a comet has elements which agree closely with those of any other on record, we conclude that the two may be two appearances of the same body, especially if the orbit is elliptical.

COMETS OF LONG PERIOD.

478. Halley's comet. — The celebrated astronomer, Halley, having computed the elements of the great comet of 1682, found that it moved in an elliptical orbit very like those of the comets of 1607 and 1531, whose orbits he also computed from observations on record. He inferred that the three comets were identical, and predicted a return about 1759.

As the time approached, great interest was aroused among astronomers, and much pains was taken to investigate the

effect of the attractions of the planets near which the comet would pass. The mathematical methods known to Halley could not have solved this problem. With improved methods, Clairaut found that the comet would be delayed by both Saturn and Jupiter, and that it would pass the perihelion within a month of the middle of April, 1759. The passage occurred March 12th.

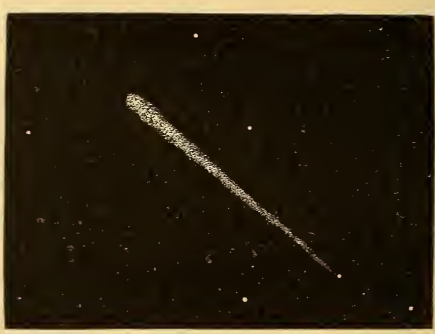


Fig. 154.—Halley's Comet, Oct. 22, 1835.

Several persons calculated its next return; the two results deemed most reliable fixed the day of perihelion for the 11th and for the 26th of November, 1835. The passage was made on the 16th. Its next appearance is expected about 1911.

From the records of comets, it appears that seven appearances of this comet have been noted, while five other dates correspond so nearly as to make it probable that they belong to the same list, extending back as far as 11 years B. C. The average period is 76 years 2 months. The orbit extends 600 millions of miles beyond that of Neptune. The motion is retrograde.

The comet of 1812, called Pons's Comet, returned in January, 1884, after a period of about 72 years, very nearly as predicted.

479. **Other comets of long period.**—No other comets of long period have verified predictions of their return. Of about 200 computed orbits, about 50 are thought to be ellipses; seven are hyperbolas, and the rest are parabolas. Most of the computed periods are long, reaching to hundreds, and even thousands, of years. A few are given for illustration:

Comet of	Years.	Comet of	Years.
1843,	376	1680,	8,813
1846,	401	1780,	75,838
1811,	3065	1844,	100,000

COMETS OF SHORT PERIOD.

480. **Ten comets** have appeared, whose calculated periods are less than 14 years, and that have returned to verify such calculations. They are all telescopic, and, but for their returns as predicted, are of little general interest. They have been named from those who have determined their orbits:

Name.	Last Return.	Least Distance.	Greatest Distance.	Periodic Times.	Next Return.
Encke's	1881, Nov.	0.342	4.10	3.304	1885, Mch.
Winnecke's	1875, Mch.	0.78	5.50	5.643	1886, June
Brorsen's	1879, Mch.	0.62	5.66	5.561	1884, Oct.
Tempel's I.	1879, May	1.77	4.82	6.00	1885, May
D'Arrest's	1883, Oct.	1.17	5.72	6.39	1890, Feb.
Biela's	1852, Sept.	0.86	6.19	6.62	....
Faye's	1880, Dec.	1.69	5.92	7.41	1888, May
Tuttle's	1871, Dec.	1.03	10.51	13.78	1885, Sept.
Tempel's II.	1883, Nov.	1.34	4.66	5.20	1889, Jan.
Swift's	1880, Nov.	1.07	5.14	5.50	1886, May

481. **Do comets meet a resisting medium?**—The period of Encke's comet is gradually diminishing, losing one

day in about ten revolutions. This indicates that some cause checks the forward or tangential force of this comet, leaving the radial force of the sun to draw it more swiftly about itself. Encke supposed that it is retarded by a resisting medium, or ether, which is densest near the sun.

The same opinion was held concerning the period of Faye's comet, but continued observation has shown that the motion of this comet is not changed. Encke's theory of a resisting ether meets little favor.

The resistance to Encke's comet may be explained by some cause other than a resisting ether. For example, the comet might meet a ring of meteoric matter, which could be a serious delay to it.

REMARKABLE COMETS.

482. A double comet.—Soon after Biela's, also called Gambart's, comet appeared in 1846, its head was seen to

Fig. 155.

become elongated or pear-shaped. In a few days two comets were seen moving side by side. The attendant, though at first smaller, gradually increased until it became brighter

than the old; afterward it diminished until it was not easily seen. Each part had its own nucleus, coma, and tail; one observer saw a stream of light, which seemed, like a bridge, to span the abyss between them. On the return of the comet in 1852, it was still divided, and the parts had become more widely separated. Since then it has not been seen, and it is now supposed to be a lost comet, perhaps wholly disintegrated.

483. **Danger of collision.**—The path of this comet lies so near the orbit of the earth that if the two bodies were to pass at the same instant they would collide, like trains at the crossing of two railways. In 1832, the comet passed this point about a month before the earth, but as the earth, though making her usual time, was then more than 45 millions of miles away, there was no occasion for fear.

Direct collision between a comet and a planet is very improbable. Arago computes the chance at one in about 287 millions. The result of such a meeting can not be guessed until more is known of the nature of comets. Many think their substance so rare, and both it and the air so elastic, that the mass of the comet could not reach the earth. We have several times passed near the tail of a comet, and Hind supposed that in 1861 the earth passed quite through one, but no effect other than a peculiar phosphorescent mist was perceived.

484. **Lexell's comet** is remarkable because its orbit has been twice changed by the force of Jupiter's attraction. It appeared in 1770, and was found to describe an elliptical orbit in about 5½ years. Surprise was felt that a comet of some brilliancy, and having so short a period, had not been seen before. By tracing its motions, Lexell found that as it passed Jupiter, it had been turned aside from its old path into a new and shorter one; that its old period had been 48 years, and its perihelion distance 300 millions of miles; at that distance it could never be visible at the earth.

485. A second change.—When the comet approached its new aphelion, which was within the orbit of Jupiter, it again found that planet in the neighborhood, and its path was a second time changed. The third orbit, though unlike either of the others, has elements which remove it from sight at the earth, where it will never again be seen, unless some adequate attraction shall change its course. Its new period is about 20 years, and its perihelion distance about 300 millions of miles.

In July, 1770, this comet passed within 1,400,000 miles of the earth, nearer than any other comet on record. Had its mass been equal to that of the earth, it is estimated

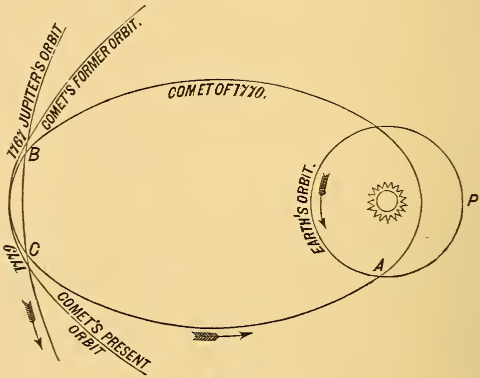


Fig. 156.

that this approach would have so changed the earth's orbit as to make the year 2 h. 48 m. longer than before. But the length of the year was not changed as much as two seconds; whence we infer that the mass must have been less than $\frac{1}{5000}$ that of the earth.

The changes in the orbit of this comet suggest that others may have been similarly disturbed. Comets that go away from the sun in parabolic orbits may wander out of the sphere of the sun's attraction and into that of some other center.

PLATE II. Oct. 5; Oct. 3; Donati's Comet. Sept. 26; Sept. 24. 1858. F. 263.

In like manner, the wanderer may come from some other system, and, passing near one of the planets, may be deflected into a new path which takes it about the sun in an ellipse of greater or less eccentricity, perhaps of short period and quick return.

486. The great comet of 1843.—On the 28th of February, 1843, a comet appeared in the day-time, quite near the sun, the head and the beginning of the tail seeming like a dagger turned from the sun. In a few days it appeared after sunset, with a tail 65° in length. When its orbit was determined, it was found that its center had passed within 80,000 miles of the sun's surface, and that the two bodies were distant not more than 32,000 miles; the heat to which it was subjected was more than 47,000 times as intense as the solar heat received at the surface of the earth, and more than 25 times that required to melt and vaporize agate and rock-crystal. Through this intensest fire, the comet whirled at a rate which increased its distance from the sun tenfold in one day. Its tail was 150 millions of miles long and 3 millions broad. Its orbit is elliptic; some have deemed it identical with the comet of 1668, having a period of 175 years. Hubbard computed its period at 530 years.

487. Other recent comets.—Donati's comet appeared on the 2d of June, 1858; in October, it was a very beautiful object in the northern sky. The nucleus was not large; the tail was about 50 millions of miles in length, very brilliant, and of very graceful form. Its period is found by Hill to be 1950 years.

The comet of 1861 was noted for its tail, which extended over more than 100°. Its period is about 450 years.

The comet of 1862 formed frequent bright jets, like jets of steam, directed toward the sun, or to the eastward, in a direction opposite to its motion. The material of each jet seemed to drift away in the direction of the tail.

The comet of 1880 is remarkable for following very closely the orbit of the comet of 1843. The comet of 1881 is likewise notable for following in the track of that of 1807. In each case, however, the orbit is so definitely parabolic, that it is quite unlikely that the second body is a re-appearance of the first.

488. RECAPITULATION.

Comets are *nebulous masses* which move about the sun in very *eccentric orbits*. They are composed of very rare material, and usually show *nucleus*, *coma*, and *tail*.

The tail is *developed* by some unknown *repulsion* in the sun as the comet *approaches*, and is probably *lost*. It is always curved *from* the *direction of motion*, and is *tubular*. The head *diminishes* as the comet comes near the sun.

The *path* of a comet is always the curve of some one of the *conic sections*, and the *motion* conforms to the great laws of *planetary motion*.

The elements of a comet's orbit are: *Inclination; longitude of perihelion; longitude of ascending node; perihelion distance; eccentricity*. Comets which have the *same orbital elements* are deemed *identical*.

Halley's comet *first returned* in accordance with prediction. The periods of ten small comets are verified by returns.

Biela's comet appeared in *two portions*, moving side by side, and is now believed to be lost.

Lexell's comet had its orbit *twice changed* by the attraction of Jupiter.

CHAPTER XX.

METEORIC ASTRONOMY.

489. **Shooting-stars.**—The bright objects which in a clear night suddenly glide along a portion of the sky, and as suddenly vanish, sometimes leaving a faint trail of light, are called *shooting-stars*. On a moonless night, a single observer may count an average of 8 an hour. As one person can see but about one fourth of the sky at once, it follows that about 30 are visible in an hour, or more than 700 in a day, if none were obscured by sunlight. But the same observations may be made from more than 10,000 stations on the earth; whence 7 millions a day pass near enough to the earth to be seen. 50 times as many may be seen with the telescope, as without, and this number increases with the power of the instrument. Professor Newton calls these bodies *meteoroids*.

490. **The November showers.**—On the 12th of November, 1833, a brilliant display of these meteors was observed throughout the eastern half of North America. Humboldt saw in South America a similar shower on the same month and day in 1799. Records were found of at least twelve other great November showers, at dates which answer very nearly to periods of 33 years. These and other facts caused the belief that these displays are periodical, and that one would occur in 1866. In America, though more meteors were counted than are commonly seen, the shower bore little likeness to that of 1833; in Europe, the scene was more brilliant, and fully confirmed the predicted return.

In 1833, it was estimated that more than 200,000 meteors were visible at a single station. The lines on which they moved, when traced backward, were all found to diverge from a single point in the group of stars called Leo, the place in the sky toward which the earth was then moving in its orbit.

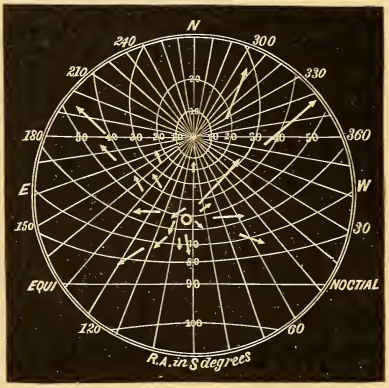


Fig. 157.

The point from which numbers of shooting-stars seem to diverge, is called the *radiant.*

491. Height and velocity. — Observations on the same meteors from distant places show that they become visible at a distance of 70 to 80 miles from the surface of the earth, and vanish at about 50 to 55 miles; that their average visible track is about 42 miles long, and the velocity is estimated at 26 to 34 miles per second. The November meteoroids move in a direction opposite to that of the earth. As the earth moves at the rate of 18 miles per second, the velocity of the meteoric body in the air must be more than 44 miles per second.

492. They do not originate in the air.—The radiant of the November meteoroids is in Leo, and remains unchanged for several hours, although the earth is rapidly turning on its axis. Hence, they must come from some place beyond the atmosphere. Their speed being about 10 miles per second greater than that of the earth in its orbit, also shows that they move independently of the earth, and at planetary rates.

493. **What are they?**—They are now believed to be planetary bodies that move about the sun in regular elliptical orbits, obeying the planetary laws. The November meteoroids are supposed to flow together in a broad and long stream or procession, in a very eccentric orbit, whose average period is $33\frac{1}{4}$ years. The orbit crosses the earth's path, and the earth passes the crossing each 12th of November, finding always some meteors. On the years before, at, and after, the interval of 33 years, the earth meets the great stream of meteors, a stream so long as to be more than two years in passing any given point, and, therefore, met by the earth, on two or even three successive Novembers.

The meteors are believed to be gaseous bodies, set on fire by friction with the air, through which they rush at such great speed; the products of combustion remain in the air.

494. **The orbit of the November meteoroids** has been computed. Its perihelion is near the earth, and its aphelion

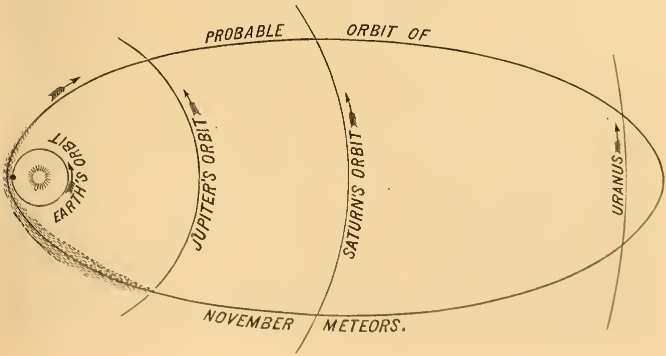


Fig. 158.

beyond Uranus. The orbit coincides closely with that of the comet of 1866, which is believed to be only a large meteor, perhaps an aggregate of several, of the November stream.

495. August meteoroids.—Many shooting-stars may be seen about the 10th of August, and a few grand showers have

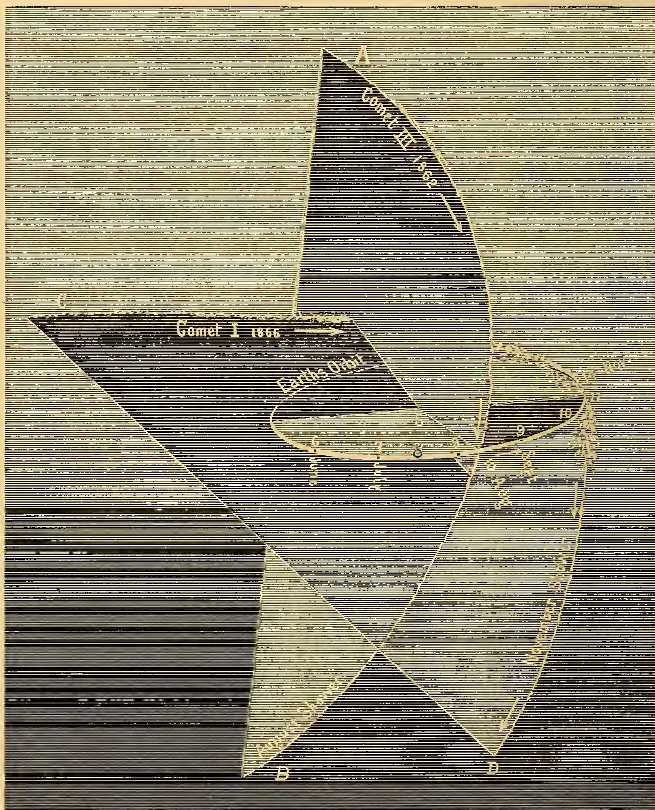


Fig. 159.—Orbits of the August and November Meteor-showers. (Orbits of Comets III, 1862, and I, 1866.)

occurred at that date. As the festival of St. Lawrence occurs on this day, the stars have been called, in Europe, St. Lawrence's tears, and the shower is known as the Laurentian

Shower. The radiant is in the group Perseus. The ring, or stream, of these meteors is believed to have a period of 105 years. Meteors constantly traverse every part of this orbit, and hence some are met every year, but at long intervals the crowd is quite dense. The comet of 1862 is referred to the August meteoric stream.

Other dates bring more than the usual number of shooting-stars. The principal are, April 18–26; December 6–13; January 2, 3.

496. **Theories suggested.** — In the discussion of meteoric rings, these items have been suggested:

That Biela's comet passed near and perhaps through the November stream, in December, 1845. The rushing stream may have divided the thin substance of the comet, as one vessel at sea cuts another in twain, in a collision. Since 1852, this comet has not been seen, although its return has been carefully watched. Has it again met a stream of meteors, to be quite broken up, material for future shooting-stars?

That the rings of Saturn may be meteoric streams, divided occasionally by the disturbing influence of the satellites.

That the Minor Planets are a stream of meteors, the largest only being visible at the earth.

That Encke's comet has been detained by meteoric streams.

That the sun's heat is maintained by the constant falling of meteoric bodies upon its surface (326).

BOLIDES.

497. **No sound** is heard from ordinary shooting-stars, probably on account of their great distance. Other fiery masses sometimes pass over the earth, followed after a time by a rushing sound or the noise of an explosion. Sometimes

the explosion and the scattering fragments have been seen; at other times the sound seems to be caused by the swift flight of the mass through the air.

The word meteor signifies any bright and transient object seen in the sky, including those just mentioned, shooting-stars, the aurora borealis, etc. Meteoric balls of fire are called *bolides*.* About 800 have been recorded.

498. **Their motions.**—In 1860, a bolis passed over the country between Pittsburg and New Orleans. Soon after it vanished an explosion was heard like the noise of many cannon. It traversed a distance of 240 miles in 8 seconds, having a velocity, referred to the earth, of 30 miles a second; referred to the sun, of 24 miles per second. Such a velocity shows that the moving body can not come from any place near the earth; the rate could not be acquired, even if it had fallen from the moon. The same conclusions follow, as in the case of the shooting-stars.

Bolides frequently appear at the dates given as abounding in shooting-stars. They are probably similar, but larger, denser, and not so soon consumed in passing through the air.

AËROLITES.

499. **In many authentic instances,** masses of mineral substance have fallen from the sky; they are called *aërolites*, or "stones of the air." The explosion of a brilliant bolis has been followed in several cases by the fall of aërolites, that buried themselves deeply in the earth, and when dug out, after some hours, were too warm to be handled. Masses of similar structure have been found, partly buried in the soil. One in the plain of Otumpa, near Buenos Ayres, was 7½ feet long, and weighed 33,000 pounds. The aërolite of

* Singular, *bolis*, from *βολις*, a missile, an arrow.

Santa Rosa, Fig. 161, reduced to one fifteenth, weighed 1653 pounds, with a volume of about 3½ cubic feet.

Fig. 160.—Meteoric Stone from Santa Rosa.

500. Their nature.—All contain meteoric iron, from one or two per cent to ninety or ninety-six per cent. The iron is malleable, and may be worked into cutting instruments. Nickel, phosphorus, silica, lime, and other elements, to the number of 22, are also found, but no new element has been discovered in them. A polished surface of meteoric iron, corroded by diluted nitric acid, shows a crystalline structure unlike common iron, but seen in iron of volcanic origin. Systems of parallel lines appear, crossed by other

lines at angles of about 60°, and producing regular triangular figures.

Fig. 161.—Section of Meteoric Iron.

501. **Meteoric dust.**—Occasional showers of black or red dust are thought to have a meteoric origin. The substance of shooting-stars which is consumed in the air can not be lost or destroyed; though it may become powder of exceeding fineness; the powder must finally fall to the earth. Dust gathered from mountain-tops has shown traces of iron and nickel, which, though comparatively rare in terrestrial minerals, are common in aërolites. Meteoric stones, dug hot from the earth, have been accompanied by a quantity of black powder. In 1813, a shower of red dust was accompanied by aërolites.

The occurrence of *dark days* has been explained by supposing that a stream of meteors passed between the earth and the sun, shutting off light and heat for the time.

THE ZODIACAL LIGHT.

502. During clear winter and spring evenings a faint triangular light streams up from the south-west, soon after dark, attracting little notice because it seems merely a continuation of the twilight that blends with it. Its direction is along the

ecliptic, and its extent usually 20 or 30 degrees; sometimes 80 or 90 degrees. In October, a similar light precedes the sun in the morning, from the south-east. It is best seen in these months because its direction is most nearly at right

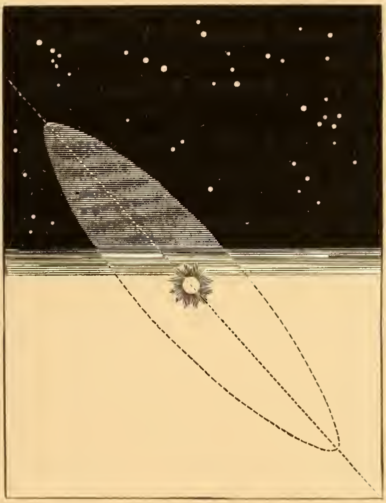


Fig. 162.

angles with the horizon, and it is least obscured by the twilight. In clear nights, between the tropics, it may be traced quite across the heavens, forming a complete ring.

503. **Its nature.**—It has been suggested that the zodiacal light is caused by a ring of meteoric bodies, which move about the sun in sufficient numbers to show a faint light, the triangular shape being caused by the obliquity of the ring. The theory more generally accepted is that the ring is composed of nebulous matter which extends beyond the orbit of the Earth, and shines by the reflected light of the sun. Its spectrum is said to give a single yellow line, and, therefore, to indicate a luminous gas.

504. RECAPITULATION.

Solid masses of mineral substances, like those found in the earth, fall from the sky.

Such masses are known to have come from *brilliant meteors* which passed the earth at a speed so rapid as to show that they were journeying round the sun.

The phenomena of *shooting-stars* indicate a similar *nature* and the same *center of motion.*

The number of shooting-stars is *infinite;* the space of the solar system is filled with them, as the air of a summer evening is filled with humming insects.

They move about the sun in *eccentric orbits,* under the same laws which control Jupiter or Neptune.

CHAPTER XXI.

THE PROGRESSIVE MOTION OF LIGHT.

The nature and properties of light are discussed in treatises on Optics. Astronomy shows that light moves and finds its rate of motion by several independent methods, which give results substantially the same.

505. Eclipses of Jupiter's Satellites. — A telescope of moderate power is able at any time to show the moons of Jupiter, hence (113) their motions are useful in determining terrestrial longitudes. Römer, a Danish astronomer,

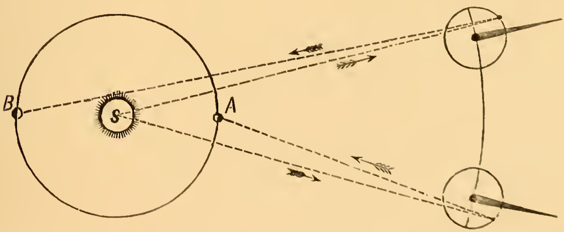


Fig. 163.

computed the times of their eclipses for a year, beginning when the planet was nearest the earth. As the planet moved away from the earth, he found that the actual time of eclipse was continually falling behind the time computed, until at

conjunction the difference was more than 16 minutes. Beyond this point, as the planets approached, the difference diminished, and at opposition had vanished.

He, therefore, inferred that the 16 minutes was the time required for light to cross the earth's orbit; that an observer at *B* would see any event at Jupiter 16 minutes later than if he were at *A*, and proportionately for intermediate distances.

Investigations of the movements of Jupiter's first satellite, from 1848 to 1873, give the time required for light to come from the sun to the earth as 8 m. 20 sec., or 500 seconds. Dividing the distance, 93 millions of miles, we find the velocity of light to be 186,000 miles per second.

So we may observe the phases of a star whose light varies regularly, as Algol (546). The real intervals must be equal; any annual variation shows the time in which the light crosses the earth's orbit. Thus it is possible to compare the velocity of the direct light of a star, with that of light reflected from a planet.

506. Aberration.—In 1725, Dr. Bradley began a series of observations upon fixed stars, to find, if possible, parallax and distance. He found that the stars in opposition to the sun,—or, as we would say, those which the earth is passing as it moves on in its path,—are moved forward about 20″ (20.445″), while those in the opposite part of the heavens, beyond the sun, are moved backward (in longitude, astronomically considered) by the same amount; those toward or from which the earth is moving are not displaced.

The difference in longitude of the same star at different seasons of the year amounts to as much as 40″, but the movement in one direction is balanced by that in the opposite direction, returning the star regularly to the same place. The relative position of star to star is unchanged, as all in the same quarter of the sky are affected similarly.

This apparent annual displacement of the stars is called *aberration*.

507. Illustration.—Suppose a rail-car, 10 feet wide, is moving at the rate of 30 feet a second; suppose a stone thrown at right angles to the track, at a rate of 20 feet a second, passes into the car at a window. The stone will cross the car in half a second, but during the half second the car will have moved forward 15 feet; hence, the stone

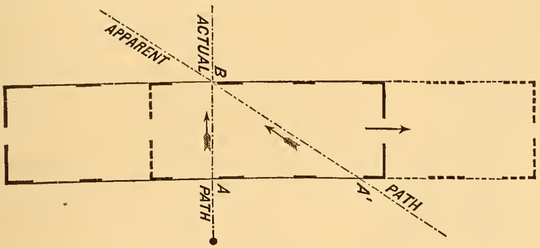


Fig. 164.

will pass out at a point 15 feet nearer to the rear of the car than the point where it entered, and that without changing its course over the track, and, perhaps, if the windows are open, without touching the car at all. To one riding in the car, the stone will seem to enter and cross obliquely, and to come from some place on the line $A'B$, rather than on the line AB, as was the fact. The apparent obliquity of the stone's motion results from the two motions of stone and car.

508. The velocity of the stone.—The stone left the car at a point 15 feet behind that at which it entered, while the car was moving 30 feet per second. As the apparent backward motion of the stone is really the actual forward motion of the car, the time was half a second; in that time the stone moved across the car, 10 feet, and its rate of motion was therefore 20 feet per second. Evidently we may, if more convenient, measure the angle $AA'B$, and the line $A'B$, and by trigonometry find the sides AB, and AA', from which the velocities of both stone and car may be determined.

509. Application.—Let AB be a telescope which moves with the earth, and in a certain time takes the position $A'B'$. Let a ray of light from the star S meet the object-glass at B, and suppose its velocity sufficient to bring it to A' at the instant that the eye-piece comes to the same point. As the ray is in the line of collimation at B and A', it must have followed that line through the tube, and there comes to the eye in the apparent direction $A'S'$, its real path having been $A'S$. The star is therefore displaced by the amount of the angle $SA'S'$ in the direction of the earth's motion.

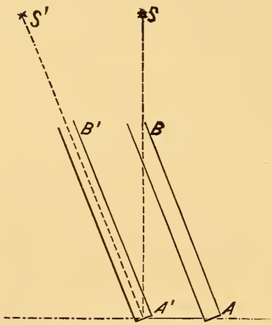


Fig. 165.

The angle is 20″ (506), and the length of the telescope is known; the solution of the triangle BAA' gives the distances AA', through which the telescope moved, and BA', through which the light moved. From the earth's rate of motion, the time of passing from A to A' is found, which is also the time of passage of light from B to A'; hence, the velocity of light is determined.

By this method, Struve finds the time required for light to come from the sun to the earth to be 498 secs.; velocity of light, 186,700 miles.

FIZEAU'S EXPERIMENT.

510. Theory.—Suppose a wheel which has 1000 teeth in its circumference rotates once in a second; evidently the time between the passage of two successive teeth is $\frac{1}{1000}$ of a second. If the wheel turns 10 times a second, each tooth marks $\frac{1}{10000}$ of a second.

Suppose a ray of light passes between two teeth of the rotating wheel, goes to a mirror at some distance, and is reflected back again. If the teeth are passing at the rate of 10,000 in a second, and the distance is such that the light can pass from the wheel to the mirror and back in $\frac{1}{10000}$ of a second, the returning ray will find the second space in the precise position for it to pass through; but if it occupies less or more than $\frac{1}{10000}$ of a second, it may find a tooth instead of a space, and be intercepted.

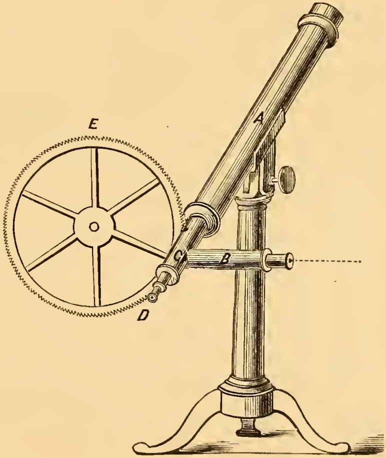


Fig. 166.

If the rate of the wheel, and the distance of the mirror are so arranged that the ray will pass through the second space, doubling the velocity of the wheel will allow the light to pass through the third space; two teeth will have passed while the light is taking its journey. Three times the velocity causes three teeth to pass, etc.

511. The apparatus.—A telescope, *A*, is fitted with a smaller tube, *B*, at right angles to the larger. The wheel, *E*, is so placed that its teeth pass through a notch in the tube, across the line of collimation of the telescope. The clock-work which drives the wheel, and registers its revolutions, is omitted in the figure, for simplicity. A ray of light from a lamp passes into the small tube, *B*, is reflected at *C* along the large tube to a mirror, at a known distance, which returns it through the large tube to the observer at *D*. The

observer can see no light which is not reflected from the distant mirror.

When the wheel turns slowly, the reflected rays are all intercepted; when the velocity is such that the rays can return in the time between the passage of two successive teeth, each finds a space to pass through, and goes to the eye, a clear bright light like a star. At a more rapid rate, the star vanishes; at double the velocity it re-appears, and again, at three and four times the velocity.

The distance from the telescope to the mirror is twice traversed, in a part of a second which is known from the rate of the teeth as shown by the clock-work, hence the velocity of light is again determined.

The experiment was made with great care, by M. Fizeau, at Paris, and has been repeated by M. Cornu.

It gave 186,600 miles per second as the velocity of light.

M. Foucault devised an experiment of a more complicated nature by which he obtained the velocity 185,200.

Foucault's method has been repeated, with some modifications, by Michelsen, at the Naval Academy at Annapolis, giving velocity 186,382.

512. RECAPITULATION.

The velocity of light as determined by

	Miles per second.
Eclipses of Jupiter's Satellites,	185,770
Aberration,	186,700
Fizeau's experiment,	186,600
Foucault's experiment,	185,200
Michelsen's experiment,	186,382
Average,	186,132

For other reasons, Michelsen's experiment is believed to be most reliable.

CHAPTER XXII.

THE FIXED STARS.

513. **The fixed stars** are those which, to the ordinary observer, keep their places with reference to each other. They are distinguished from a few which, from their wandering, were called planets (117). The fixed stars form groups nearly the same as those which were seen two thousand years ago; careful observations with the telescope, compared after the lapse of many years, show that some of them do move. Probably none are absolutely fixed in space. Besides keeping its place, a fixed star usually maintains the same brightness and color from century to century.

514. **Magnitudes.**—The stars are classed by their brilliancy, the brightest being of the *first magnitude.* Stars larger than the seventh magnitude, and, under very favorable circumstances, even those of the seventh, may be seen without instruments. Smaller, or telescopic, stars are classed as low as the 18th, or even the 20th, magnitude. The only limit is the power of instruments.

Sirius is by far the brightest star in the sky, and no other is entitled to rank with it. Sixteen to nineteen other bright stars are usually classed with Sirius, in the first magnitude, although it is not easy to say why the division should be made either at the seventeenth, or at the twentieth.

515. **The relative brightness of the magnitudes.**—Herschel proposed to indicate the relative brightness by

numbers. He placed two telescopes in such positions that he could pass very quickly from one eye-piece to the other. He then prepared a series of pasteboard rings, with openings of various sizes; with these rings, laid over the object-glass, he could admit more or less light, as he pleased. When comparing two stars, he reduced the light of the brighter until it seemed no more than that of the less. Then he considered that the magnitude of the stars were proportioned inversely to the areas through which their lights were received.

Thus, when he covered three fourths of the object-glass, Arcturus, a star of the 1st mag., seemed no brighter than Polaris, of the 2d mag.; hence, Polaris is one fourth as bright as Arcturus. In the same way, Polaris is found equal to four times Mu Pegasus, of the 4th mag., and Mu Pegasus is equal to four times q Pegasus, which is between the 5th and 6th mags. Hence, the brightness of Arcturus is

4 times that of a star of the 2d mag.;
16 times that of a star of the 4th mag.;
64 times that of a star between the 5th and 6th mag.

Working by this method, he found the average brightness of the magnitudes as follows:

Sirius, brightness 320.

Mag.	Av. bright.	No. of stars.	Mag.	Av. bright.	No. of stars.
1	100	20	4	6	300
2	25	40	5	2	1000
3	12	150	6	1	4500

Zöllner compares the light and color of a star with an artificial star, whose light can be varied at pleasure. The results of this method are yet to be published.

516. The number of the stars.—In the whole heavens, about 6000 (5905) stars may be seen without a telescope.

As but half the sky is visible at once, and only the brightest stars can be distinguished within several degrees of the horizon, probably not more than 2500 can be seen at once. That the "stars of heaven" should seem to be "countless," is due partly to their irregular distribution, and partly to our inability to comprehend, and, therefore, to apply, large numbers. The number of a body of soldiers always seems less when the men are in order, than when scattered; the number of persons in a crowd is always overrated.

The number of stars above the 10th mag. is placed at about 200,000, while it is estimated that more than 20 millions are visible with Herschel's 18-inch reflector. Instruments of greater power reveal yet greater multitudes. The number of stars in the universe is beyond the conception of the human intellect—is *infinite*.

CONSTELLATIONS.

517. **In early ages,** the groups of stars received names which have been retained to the present time. Some, as the Bear and the Bull, came from a fancied resemblance to the forms of those animals in the outlines of the groups; most were derived from the ancient mythologies—from gods or heroes, who left the earth and were transfigured in the skies.

518. **Modern constellations.**—The part of the sky about the south pole was not known to ancient astronomers. The outlines of the old constellations did not exactly fit each other, and many patches of sky lay between, which did not belong to any. From these two sources, modern astronomers formed new groups, to which, from motives of gratitude, of flattery, or of caprice, they gave names of distinguished men, of princes, of animals, or of scientific instruments.

The whole number of recognized constellations is 117.

519. The Zodiac.—Twelve constellations along the ecliptic, extend about eight degrees on either side, forming a belt 16 degrees wide, called the *Zodiac*.* They are

Aries, the Ram;	Libra, the Scales;
Taurus, the Bull;	Scorpio, the Scorpion;
Gemini, the Twins;	Sagittarius, the Archer;
Cancer, the Crab;	Capricornus, the Goat;
Leo, the Lion;	Aquarius, the Waterman;
Virgo, the Virgin;	Pisces, the Fishes.

520. The signs of the Zodiac.—Although these constellations occupied the entire circuit of the sky, they did not divide it equally. The zodiac was therefore divided into 12 equal parts, called *signs*, each 30° in extent. To each sign was given the name of the constellation which lay mostly within it. Thus, the first sign, which extended 30° from the vernal equinox, was called Aries, because, when the zodiac was divided, it contained the constellation Aries.

521. The signs have moved backward.—The vernal equinox moves backward, or westward, along the ecliptic, about 50″ a year, the autumnal equinox following at 180°. The equinoxes seem, therefore, to go *toward* the sun; their motion is called *the precession of the equinoxes* (App. V). Since the division of the zodiac, the equinoxes have moved about 28°, and the *sign* Aries now contains the *constellation* Pisces.

The number of seconds in the zodiac, divided by the annual motion of the equinox, gives the time in which it will make the entire circuit of the sky; it is about 26,000 (25,870) years. From a similar computation, La Place supposes that the division of the zodiac into signs was made about 2500 years B. C.

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* Greek, Ζωδιακός, zodiakos (κύκλος, kuklos, a circle, understood), meaning *a ring of animals.*

522. The northern constellations.—The most notable are

Andromeda;
Aquila, the Eagle;
Auriga, the Wagoner;
Corona Borealis, the Northern Crown;
Cygnus, the Swan;
Draco, the Dragon;
Hercules;
Lyra, the Lyre;
Boötes,
Cassiopeia;
Cepheus;
Ophiuchus;
Pegasus, the Winged Horse;
Perseus;
Ursa Major, the Great Bear;
Ursa Minor, the Little Bear.

523. The southern constellations.—The principal are

Argo Navis, the Ship Argo;
Canis Major, the Great Dog;
Canis Minor, the Little Dog;
Centaurus, the Centaur;
Cetus, the Whale;
Crux, the Cross;
Eridanus;
Monoceros, the Unicorn;
Orion;
Piscis Australis, the Southern Fish.

524. Names of the stars. — After the constellations were named, it was usual to indicate a star by the place which it occupies, as, the Lion's heart, the Bull's eye, the ear of Virgo, the girdle of Orion. Many of the brighter stars have names of Latin, Greek, or Arabic derivation. Such are Regulus, Capella; Sirius, Arcturus; Aldebaran, Algol.

525. The stars indicated by letters.—In 1604, Bayer, a German, published maps of the sky, in which the stars of a given constellation were indicated by the letters of the Greek alphabet, the brightest being α, alpha; the next, β, beta; the third, γ, gamma, and so on. When the 24 Greek letters were exhausted, he used the Roman letters, and then numbers. Thus, α Draconis, means the brightest star in the Dragon; β Persei, the second star in Perseus; *b* Orionis,

the 26th of Orion; 61 Cygni, the 111th of the Swan. It appears that Bayer did not indicate the order of the stars from any observations of his own, but according to their magnitudes as given by Ptolemy and Tycho Brahe. The letters do not now always give the order of brightness; as an example, either β or γ Draconis, is brighter than α of the same constellation.

526. **Catalogues of stars.**—Several have been made, the stars being entered by right ascension and declination, in the order of right ascension. The first, by Hipparchus, B. C. 128, contains 1025 stars.

Among the most important modern catalogues are the following:

Name	Date.	No. Stars.
The British Association,	1845,	8,377
Lalande's,	1801,	47,390
Bessel's,	1846–63,	62,000
The zones of Argelander,	1859–62,	324,000

References are made by the name of the catalogue and the number of the star.

NATURE OF THE STARS.

527. **The stars are suns.**—The polariscope shows that the light of stars has not been reflected; they are, therefore, self-luminous. But the only self-luminous body which we know in the sky is the sun; hence, we conclude that the stars are suns, and that the sun of our system shines as a star, if seen at a like distance. We may farther suppose that the stars, like our sun, are centers about which systems of planets, satellites, and comets, revolve. We shall find reason to believe that some of the stellar systems are far more complicated and wonderful than our own.

The stellar light, analyzed by the spectroscope, indicates that elements exist in the stars which are identical with those found in the sun and in our earth, together with others unknown in either sun or earth, materials utterly unknown and inconceivable.

528. Stars in the telescope.—To the naked eye, a star is a bright point surrounded by rays. The telescope cuts off the rays, and so diminishes the apparent breadth, while it increases the brightness. A planet shows a disc, like a little moon; a star does not.

The brighter stars, in the best telescopes, seem to be exceptions; but the disc in these cases is believed to be caused by the dispersion of light in our atmosphere, and not to be real. If a disc of appreciable breadth were really seen, it should increase with higher magnifying power; when hidden by the moon, the star should vanish at the moon's edge gradually, rather than instantly as is the fact.

529. How are the stars visible?—They show no disc. They are, therefore, seen only by the *intensity* of their light. The star is at the center of a sphere which it fills with light that diminishes in intensity as the square of the distance increases. The pupil of the eye admits a certain amount of this light, and the lenses condense it upon the sensitive retina. If the condensed beam is intense enough, it excites the nerve, and we see the star; if not, the star is invisible.

The telescope, by its object-glass, or its speculum, gathers up as much more light as its cross-section is larger than the pupil of the eye. This greater amount of light, condensed by the lenses and passed to the eye, may be intense enough to make itself visible; thus the telescope reveals stars which the unassisted eye can not see.

530. Why do stars differ in brightness?—By difference in distance, and difference in size. If the sun were twice as far from us as now, its light would be one fourth as intense; at three times the distance, the light would be $\frac{1}{9}$; at

ten times, $\frac{1}{100}$, etc. The proof is precisely the same as that for varied attraction of gravitation (157). If the stars are suns of equal size and brilliancy, those that are brightest must be nearest, and conversely, according to the law. But among the nearest fixed stars are some of small magnitude. We, therefore, conclude that the different glory of the stars depends upon both size and distance.

531. Their brilliancy compared with that of the sun.—Wollaston found that the sun's light is 800,000 times that of the full moon, and that is 27,000 times the light of the star Alpha Centauri, of the first magnitude. Hence, at the earth, the sun's light is 21,600 million times that of Alpha Centauri. But that star is 224,000 times as far away as the sun; if it were brought as near as the sun, its light would appear $224{,}000^2 = 50{,}176$ million times as great as now, or about 2.4 times that of the sun.

In a similar way, we find that Sirius is a center of light and heat 393.7 times larger and grander than our sun.

DISTANCES TO THE STARS.

532. The distances to some of the fixed stars may be found approximately by methods similar to those explained in Chap. IX.

Frequent measurements with the micrometer show that the distances between some of the fixed stars and their neighbors are variable. A star that is near the ecliptic seems to move back and forth on a short line annually. Another, near the pole of the ecliptic, describes a small circle; and others, between the ecliptic and its pole, move in ellipses which are flattest when nearest the ecliptic.

The cause of this apparent motion can be neither refraction nor aberration (506), because either of these would affect alike all the stars in the same part of the sky. When one

star appears to approach another, and then to recede from it, annually, we suppose, first, that the apparent motion is caused by the actual annual motion of the earth in its orbit; second, that the star which seems to move is much nearer than that which appears stationary.

The base-line (Fig. 167) is now the axis of the earth's orbit, and the angle of parallax is the angular motion of the star during half a year.

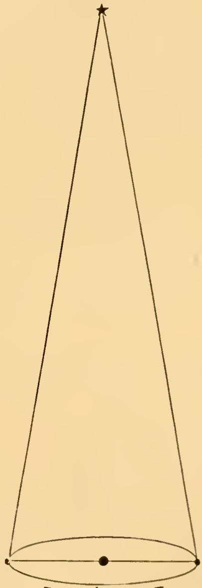

Fig. 167.

533. **Results.**—As our measuring rod is now the radius of the earth's orbit, our results will be in that denomination. We may express them in millions of millions of miles, but these numbers are beyond our grasp. By walking nearly 30 miles a day, a man might travel 10,000 miles in a year, or one million miles in 100 years. At that rate, the journey to the sun would require 9300 years; if Adam had begun at his creation and traveled until now, he would have completed less than two thirds of his task! How shall we comprehend distances whose unit of measure is so vast?

534. **Alpha Centauri.**—This star has an annual parallax of 0.92″. This gives a distance of 224,000 times the radius of the earth's orbit, or 20,832,000 millions of miles. At 30 miles an hour, a rail-car will run 263,000 miles in a year—a little farther than to the moon. The car must continue its unvarying speed for about 80 millions of years to reach this star. A cannon-ball, flying at the rate of 1 mile in 5 seconds, would expend 3,300,000 years in the journey. Finally, light itself, the swiftest agent we know, which traverses 186,000

miles in a single second, will have been more than 3½ (3.55) years in coming from Alpha Centauri to our eyes.

Yet Alpha Centauri, so far as we know, is our *nearest neighbor among the stars.*

535. **Other stars of known parallax.**—The times and distances in the following table, from Arago, for four of the nearest fixed stars are not supposed to be exact. They are only the smallest round numbers which the conditions of the problem admit.

Star.	Distance from earth, in millions of millions of miles.	Time required for passage of light, in years.
Alpha Centauri,	20	3.6
Sirius,	127	21.5
Arcturus,	152	25.5
Polaris,	286	48.3

536. **Distances of smaller stars.** — We may reasonably suppose that some, even of the smallest telescopic stars, are, in fact, bodies as large as Alpha Centauri, and seem small by reason of their greater distance. Referring again to Herschel's method of comparing the brightness of stars, and remembering that the intensity of light diminishes as the square of the distance increases, we find that, at twice its present distance, Arcturus, a star of the 1st magnitude, somewhat less than Alpha Centauri, would be as bright as a star of only the 2d mag.; at four times its distance, it would appear of the 4th mag.; at twelve times its distance, of the 6th mag. Hence, we suppose that some stars of the 6th mag. are at least twelve times as remote as Alpha Centauri, and that their light is at least 43 years in coming to the earth.

Evidently much greater results would come from a comparison with Sirius or Polaris.

537. **Distance of telescopic stars.**—A star of the 6th mag. is just visible to the naked eye. A telescope whose object-glass has *twice* the diameter of the eye-pupil, has four

times the area, and admits *four times* the light; it will, therefore, reveal a star which is *twice* as distant as a star of the 6th mag. So one of three times the diameter of the eye-pupil, would show a star three times as far away.

The pupil of the eye is ordinarily about one eighth of an inch in diameter; the object-glass of the great Washington refractor has an opening of 26 inches, or 208 eighths of an inch. Hence, the Washington refractor will show a star of the actual size of Alpha Centauri, when removed 208 times as far as a star of the 6th magnitude; and the light of that star would require more than 208 × 43 years, or more than 8900 years, in coming to our eyes. Were such a star blotted from the firmament when Adam began to till the soil of Eden, the last installment of its expiring light, now on the way, would not yet have reached the earth.

538. Results.—Light occupies, in coming to the earth from the nearest star of the

1st mag.,	more than	3.6	years.
2d "	of same actual size,	7.2	"
4th "	" "	14.4	"
6th "	" "	43.	"
From smallest stars in Washington refractor,		8900.	"

Immense as these distances seem, astronomy teaches of yet greater depths of space.

VARIATIONS OF STARS.

539. They have become less bright.—Eratosthenes says of the stars in the scorpion, "they are preceded by the most brilliant of all, the bright star of the northern claw." The star of the southern claw is now brighter than that of the northern, while Antares, of the same constellation, is brighter than either. Stars which Flamsteed and Bayer recorded in their catalogues as of certain magnitudes, are now classed in much smaller magnitudes.

540. **Stars have vanished.** — Many stars of the old catalogues can not now be found; probably most of these entries were erroneous, but some stars are known to have disappeared. The 55th of Hercules was recorded by Bayer as of the 5th mag. In 1781, Herschel saw it and noted its red color in his journal. In 1782, he noted it again. In 1791, he saw no trace of it, and it has not since been seen.

541. **They have become more brilliant.** — Several stars in Flamsteed's catalogues are classed in higher magnitudes by Herschel. A small star near Mizar, the middle star of the handle of the Dipper, was called Saidak, the *proof*, by the Arabs, because the ability to see it was a test of very keen eyesight. It is now easily seen.

542. **Variations of color.** — Single stars show great variety of color, running through shades of red, yellow, blue, and green. Some have changed color. Sirius, which ancient astronomers describe particularly as red, has to modern observers shone with purest white, and of late shows a light emerald green. Aldebaran, Antares, and Betelgeuze are red; Arcturus is orange; Capella, bluish. How strange would the world appear to human eyes, if the sun should shed only blue, red, or orange light!

543. **Stars have appeared.**—The appearance of a new star is said to have suggested to Hipparchus the idea of making a catalogue of the stars. This statement was supposed to be mere fiction until the appearance of the same star was found recorded in the Chinese annals.

New star of 1572. — This star, observed by Tycho Brahe, November 11, appeared in the constellation Cassiopeia. In size, it surpassed Sirius, and it could be compared with Venus when she is brightest. It was seen in the daytime, and at night through clouds of considerable density. Its position was carefully found, to make sure that it did not move, and was not a comet. In December its brightness

began to diminish, and it gradually passed through the degrees of brightness until March, 1574, when it vanished, having been visible seventeen months. Its color was first white, then yellow, finally red.

544. **Other new stars.**—A temporary star appeared in Ophiuchus, in October, 1604. In November it was brighter than Jupiter. It gradually diminished, and after remaining visible fifteen months disappeared.

In 1848, Mr. Hind observed a new star in Ophiuchus; after a few weeks, it waned from the 4th to the 12th mag.

In May, 1866, a star of the 2d magnitude appeared in the Northern Crown; in June, it was of the 9th mag. Many other instances might be cited.

545. **Periodic stars** increase and diminish in brightness at regular intervals. About 100 are known, having periods which vary from a few days to many years. Stars which have become more or less brilliant, and even the temporary stars, may yet be found to be periodic.

546. **Algol.**—This most remarkable of all the periodic stars, also called Beta Persei, is in the head of Medusa. It is of the 2d mag. for 2 days 13 hours; it then changes, in 3½ hours, to the 4th mag.; and in 3½ hours more, returns to its former brightness. Its entire period is about 3 days (2 d. 20 h. 48 m. 55 s.). Its variation has been observed about 200 years.

547. **Mira.**—Because of its variation Omicron Ceti was named *Mira*, The Wonderful. This star is of the 2d mag. for about 14 days; it then diminishes until, after about two months, it is invisible without a glass, being of the 9th or 10th mag. After six or seven months it re appears, and in two months more recovers its greatest size. It makes this circuit on an average of about 331 days; but the period varies about 25 days in 88 changes.

548. **The causes** of these periodic changes are not known. Several theories have been suggested.

1. That the star is a body which, like the sun, has many dark spots, or which emits light from only one side, and that it rotates, presenting alternately its bright and dark sides.

2. That the rotating body is flat like a millstone, and presents first its broad surface, then its edge.

3. That a dark body, or planet, revolves about the bright central body, and thus shuts off the light.

4. That a nebulous mass revolves about the star, gradually intercepting the rays, and as gradually restoring them. This theory has fewest objections.

5. Newton suggested that a body, before invisible, had been set on fire by collision with a comet, and remained visible until consumed.

DOUBLE STARS.

549. Although all stars seem single to the naked eye, the telescope resolves many into two, and some into several, distinct bodies. In 1780, Herschel knew but four double stars. He increased the number to 500, and now many thousands have been entered in star catalogues.

Some are separated by telescopes of low power, others require instruments of great power, and of very delicate definition. The most important part of a refractor is its object-glass. If its surfaces are accurately ground and polished, and its material is of equal density throughout, this glass gathers all the light which passes through it into a single point, the focus. An imperfection in either respect causes some rays to fall short of the focus, or beyond it, and the image is a little indistinct. The eye-piece can not cure this defect; it can only magnify the imperfect image. This exact defining power is the precise quality needed to resolve some of the double stars; there must be entire absence of blur.

550. **Stars optically double.**—The components of a double star may be only apparently near; one may be far beyond the other, in almost the same line of sight. Indeed, one may conceal another which is exactly behind it. But such apparent nearness of bodies which have no relation to each other could not often occur.

551. **Binary stars.** — Herschel, supposing that double stars were only optically double, expected that they would give fine opportunities for observing annual parallax, and thus for finding distances. He soon found that, in most cases, each has the same apparent annual motion, and, hence, that the two must be about equally distant. After about twenty years' labor, he could say that in certain cases one component describes an orbit about the other, thus proving a physical relationship. A star which is single to ordinary vision, but which may be resolved into two stars thus physically related, is a *physically double*, or *binary star*.

552. **The components** of the same star are rarely of the same brightness or color. The parts of Alpha Centauri are of the 1st and 2d magnitudes; of Gamma Virginis are each of the 4th; of 70 Ophiuchus, 4th and 7th; of Polaris, 2d and 9th. The colors of some double stars are complementary, that is, such as together produce white light. A faint white near strong red often seems green; if the near and strong light is yellow, the white light appears blue. Many of the pairs of color can not be explained by contrast. From a long list a few are selected.

Star.	Color of large member.	Color of small member.
Gamma Andromedæ,	Orange,	Sea-green.
Alpha Piscium,	Pale Green,	Blue.
Eta Cassiopeiæ,	Yellow,	Purple.
Zeta Coronæ.	White,	Light Purple.
Kappa Argus,	Blue,	Dark Red.
Star in Centaurus,	Scarlet,	Scarlet.
Iota Cancri,	Bright Yellow,	Indigo Blue.

553. **Revolution.**—We have already remarked that one of the components of a star physically double moves about

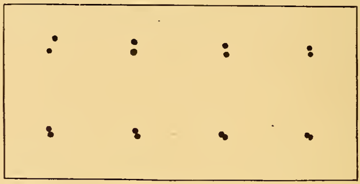

Fig. 168.

the other. The diagram, Fig. 168, shows the observed positions of the two parts of Gamma Virginis; and Fig. 169, the orbit derived from these observations. In Fig. 169, in

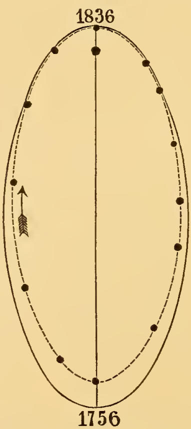

Fig. 169.—Gamma Virginis.

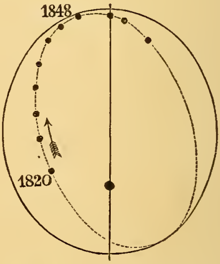

Fig. 170.—70 Ophiuchi.

Fig. 170, 70 Ophiuchi, and in Fig. 171, Alpha Centauri, the full line shows the true shape of the orbit, while a dotted line shows the orbit as seen from the earth, obliquely.

554. **Time of revolution.**—Of the stars known to be physically double, twelve have periods less than a century;

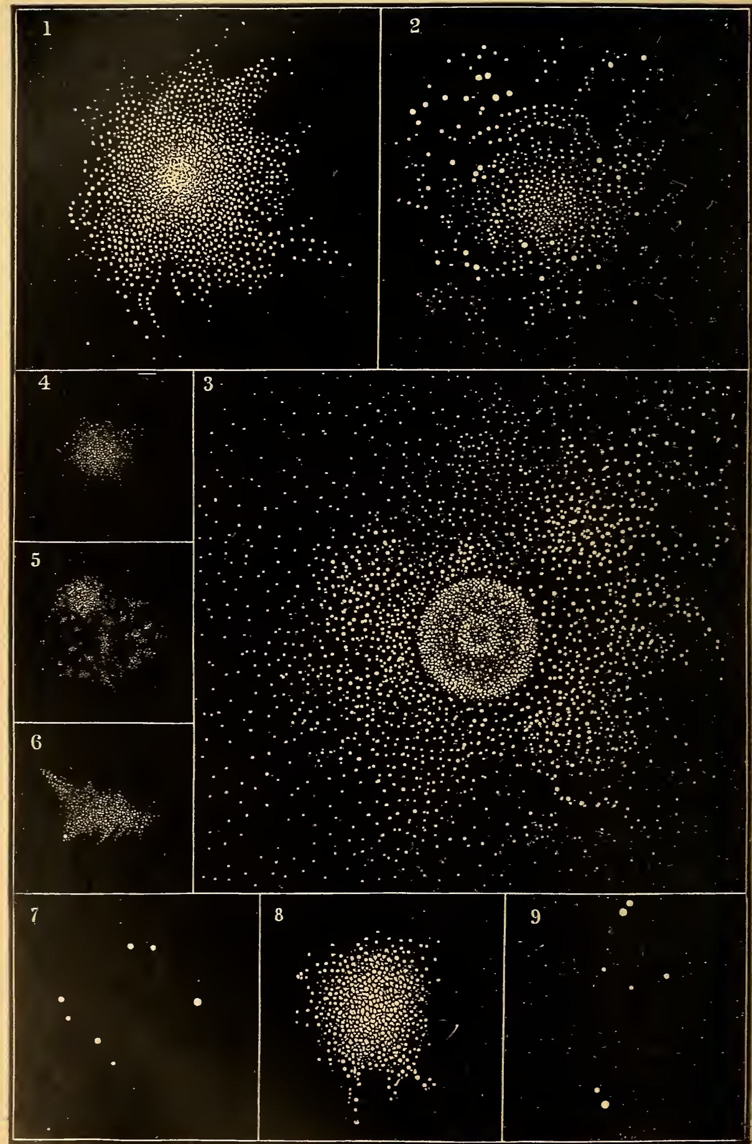

PLATE III.—1, Star Cluster in Hercules. 2, in Libra. 3, in the Toucan. 4, in Pegasus. 5, in Canes Venatici. 6, in Cepheus. 7, Theta Orionis. 8, in Capricorn. 9, Eta Lyræ.

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about 400 seem to require more than 1000 years to complete a single revolution. The time during which these stars have

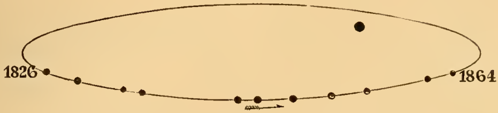

Fig. 171.—Orbit of companion to Alpha Centauri.

been studied is too short to admit an accurate determination of their periods. Probably most of the double stars will prove to be physically connected.

The periods of a few are:

Zeta Herculis,	35	years.
Sirius,	50	"
Xi Ursæ Majoris,	63	"
Alpha Centauri,	77	"
70 Ophiuchi,	93	"
Gamma Virginis,	182	"
61 Cygni,	452	"

MULTIPLE STARS.

555. **Zeta Cancri.**—This star has three members, two of which revolve about the third. Since 1782, the nearer of the companions has made nearly two complete revolutions, the period being 58 years; the more distant has passed over rather more than 37° of its orbit, indicating a period of more than 500 years.

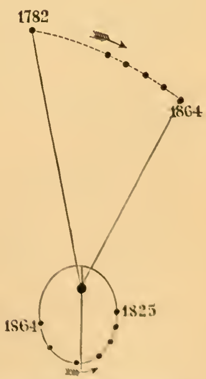

Fig. 172.—Zeta Cancri.

556. **Theta Orionis.** — A good telescope resolves this star into four components, arranged as in Fig. 7 of Plate III.; instruments of higher

power show that each of the two lower stars has a companion, and of late a seventh star has been found in the group. It does not yet appear that these stars are physically connected; they do not appear to have changed their relative position since they were first observed by Herschel.

557. The stars obey the laws of gravitation.—The members of such binary and ternary systems as have motion are found to obey the great laws of Kepler. The orbits in which they revolve are ellipses; the radii vectores describe equal areas in equal times. Thus it appears that the laws of gravitation and of planetary motions are indeed UNIVERSAL.

The companions of Alpha Centauri and Gamma Virginis move in orbits which are very eccentric; more than those of any of the planets in our system.

The motions of certain stars, Procyon for example, indicate the presence of companions or satellites as yet invisible.

558. Dimensions of stellar orbits.—The distance of Alpha Centauri is believed to be about 224,000 times the distance of the sun. The orbit of its companion has a major axis which subtends an angle of 30″; from this it appears that the mean radius of this orbit is about 16 times the mean radius of the earth's orbit, or about 1488 millions of miles—four fifths the distance of Uranus from the sun.

The radius of the orbit of the companion of 61 Cygni is about 44 times that of the earth's orbit, or about 4000 millions of miles. Its orbit is considerably larger than that of Neptune.

559. Masses of the double stars.—We apply to the stars whose companions move at known distances the same method for finding mass which was used in finding the mass of Jupiter, or of any planet which has a satellite. From this it appears that the sum of the masses of components of the star of Alpha Centauri is 0.7 that of the sun; 61 Cygni, 0.3 that of the sun; 70 Ophiuchi, about 3 times the sun. Thus does the astronomer weigh even the stars in a balance.

CLUSTERS OF STARS.

560. **The Pleiades,** or Seven Stars, is a noted cluster in the neck of Taurus. Six stars may be easily counted, and glimpses of many more may be seen with the naked eye; some persons distinguish twelve or fourteen. The telescope shows about an hundred. The largest star, Alcyone, is near the ecliptic. Certain theorists have supposed that the center of the universe is in this star, and that solar and stellar systems revolve about it; the theory is not sustained by astronomical research.

The Greeks called this group the Pleiades, from their word *plein*, to sail, because the Mediterranean was navigable without danger, when they rose and set nearly with the sun.

561. **Other clusters of note.**—A bright spot in Cancer, called Præsepe, or the Manger, is resolved by the telescope into a cluster of stars.

A cluster in Hercules, which to the naked eye shows a hazy spot of light, makes a magnificent display when viewed with a powerful telescope. The stars are scattered somewhat thinly near the edge of a nearly circular space, but growing more numerous toward the center, blaze there, a dense mass of most brilliant gems (Plate III., Fig. 1).

In Centaurus a still richer cluster is found. Without the telescope, it seems a hazy star of the 4th magnitude; but in the instrument, it appears a globular mass of stars, too numerous to count, and covering a space two thirds as broad as the moon.

The most beautiful specimen is the splendid cluster in Toucan (Plate III., Fig. 3), in a region of the southern sky quite devoid of stars. There are three distinct gradations of light about the center; the orange red color of the central mass contrasts wonderfully with the white light of the concentric envelopes.

562. Astral systems.—We must believe that the stars in these groups are within the sphere of mutual attraction; they must, therefore, be in motion. But their distance from us is so great, that the separate stars of which they are composed may be as far apart as the sun is distant from the nearest fixed star. These clusters are, then, grand systems of suns, moving in harmony about one common center. We may call them *astral systems.*

NEBULÆ.

563. The word nebula means a mist or cloud. In 1682, Simon Marius observed in the constellation Andromeda a spot about 2½° long by 1° broad, which gives a dim light like "that of a candle seen through a thin plate of horn." Huyghens found another such spot in the sword of Orion. Because the light from these spots is misty, they are called *nebulæ*, clouds.

As the making of star catalogues progressed, more were discovered, while each improvement of the telescope has revealed yet greater numbers. Herschel noted over 2500, and more than 5000 are now recorded.

564. Appearance.—Nebulæ are faint patches of light, with the same ragged outlines which star-clusters show to the naked eye. The telescope resolves many into clusters; each more powerful instrument, while it discovers new nebulæ, resolves some of those before known. Some show a ground of nebulous light studded with stars. Others, and among them some of the longest known and most carefully observed, have resisted the highest powers, and the most accurate definition.

565. The spectroscope.—As one nebula after another was resolved by the telescope, many were led to suppose that all would yield to suitable instruments, that all nebulæ are clusters of stars.

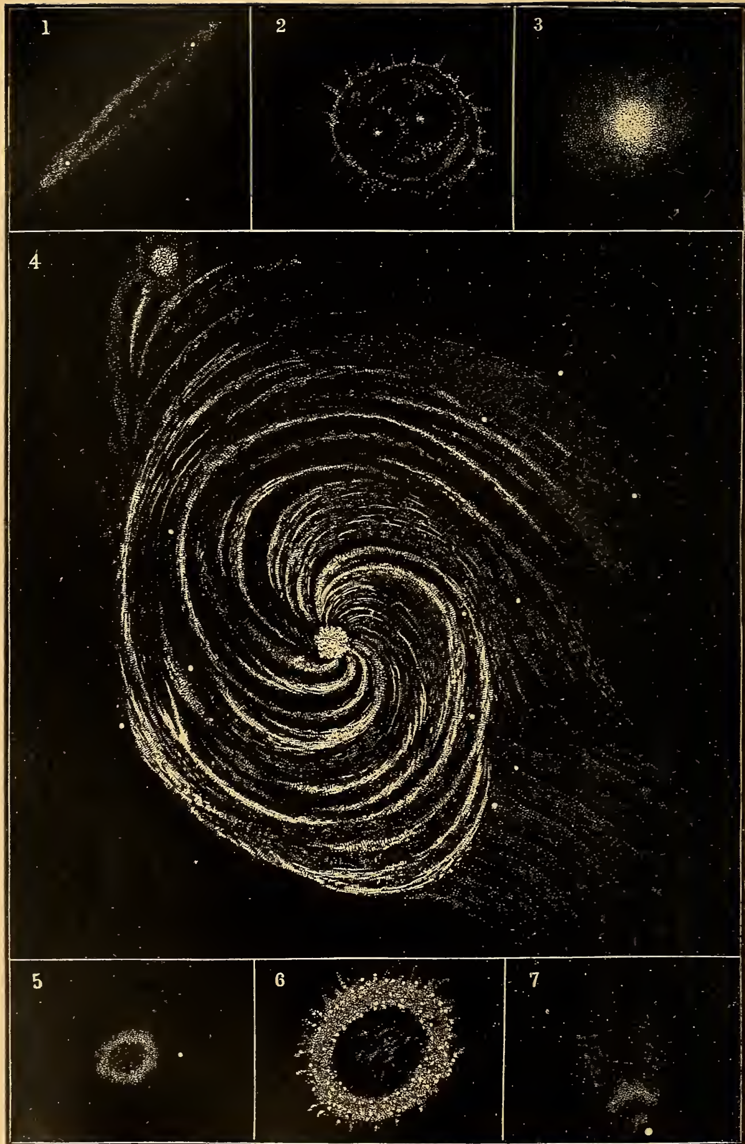

PLATE IV.—1, Nebula in Andromeda. 2, in Ursa Major. 3, in the Virgin. 4, Great Spiral in Canes Venatici. 5, in Lyra (Herschel). 6, the same in Lyra (Lord Rosse). 7, in the Unicorn.

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In 1864, Mr. Huggins analyzed the light from a nebula in Draco, and found that it is not compound, like sunlight, but that the rays come from a glowing gaseous substance, devoid of any atmosphere. The lines in the spectrum indicate the existence of hydrogen, nitrogen, and a third substance not recognized.

Hence, it seems certain that *some* nebulæ are not star-clusters, and that no delicacy of instrument can ever resolve them. They may be much nearer than has hitherto been supposed.

566. **Their forms** are various. Even the same nebula shows very different shapes in instruments of different powers.

The spherical are most common. These have a circular outline, from which the light gradually increases toward the center; they resemble star-clusters. When a bright point appears in the center, the nebulæ is a *nebulous star;* if the light is quite equally diffused over the whole disc, it is a *planetary nebula.*

567. **Elliptical.**—Some have an elliptical outline like that of a disc seen obliquely. The great nebula of Andromeda (Plate IV., Fig. 1) is shaped like a convex lens seen edgewise. One near Cygnus has an oval outline, surrounding a brighter figure somewhat resembling a dumb-bell.

568. **Annular.**—A nebula in Lyra shows an oval ring which surrounds a space of fainter light, as if thin gauze were stretched across the ring. Lord Rosse's telescope resolves the ring into bright points, and shows faint bands of light across the opening; the ring seems bordered with a fringe. Other rings show two bright points at opposite ends of a diameter. Another has the ring drawn out into a narrow ellipse, and the two bright points are at the ends of the opening (Plate IV., Figs. 5 and 6).

569. **Spiral.**—A nebula in Canis Venatici shows to Herschel II. a large bright globular cluster, surrounded by a ring

at a considerable distance from the globe, varying much in brightness, and for about two fifths of its circumference divided into two parts, one of which appears raised up from the other; near it is a small bright globe. Lord Rosse's telescope reveals splendid lines of light which pass spirally from the central globe to the ring, while other spiral lines connect the outer globe with the rest of the system. The whole is thickly strewn with stars (Plate IV., Fig. 4).

A nebula in Virgo shows a bright central spot, like the nucleus of a comet, surrounded by four broad spiral branches like tails, each being divided by dark lines into numerous spiral threads.

The spiral nebulæ now known number about 40, and as many more are supposed to have this form.

570. **Irregular.**—Most nebulæ are included in some of the foregoing classes, whose regular forms indicate some central force of attraction, and, consequently, some motion of the parts. A few are too irregular, so far as they are yet observed, to indicate any such conformity to law.

The lens-shaped appearance of the nebula of Andromeda, already mentioned (563), is changed under high powers into the irregular outline in Fig. 2, of Plate V. Two dark furrows seem to have been plowed through the middle of it, and the whole surface is sown broadcast with stars.

The Dumb-bell nebula (Plate V., Fig. 3) also shows a profusion of stars, under high powers. The general outline is the same as with low powers, but the bright inner figure is much changed.

A nebula in Taurus (Plate V., Fig. 1) is oval in ordinary telescopes; in Lord Rosse's reflector it resembles a huge crab, with legs formed of strings of stars.

The nebula of Orion is too irregular to be described. The drawings of Bond, Struvé, and Secchi show that it has changed considerably since it was first figured by Herschel. Struvé says that the central part is continually agitated like the surface of the sea.

Other nebulæ are as irregular and as ill-defined as a mottled summer-cloud, and the causes which determine their shape can be as little understood.

571. **Nebulous stars** are masses of nebulous light surrounding one or more bright points (566). Some have a single point at the center; others, a point at each focus of the curve of outline; one has three at the angles of an equilateral triangle; a long nebula has two stars at the ends of its longest diameter.

These points are supposed to be centers about which the nebulous matter is accumulating. They have also been thought to be suns surrounded by dense atmospheres, made visible by the transmitted light, as a fog becomes visible about a lamp.

572. **Double nebulæ.**—As we find double and multiple stars, so we find double and multiple nebulæ. In these grouped lights, are seen the same varieties of form which appear in the single nebulæ. We find associated two globular masses; two elliptical masses; an elliptical with a globular mass (Plate V., Fig. 7); two globes surrounded by bright arcs, like fragments of a broken ring (Plate V., Fig. 6); and, finally, a large elliptical mass of light, on whose outer edge are scattered, not very regularly, seven smaller globose masses, as small bunches are seen growing on a larger potato (Plate V., Fig. 5).

THE MILKY WAY.

573. **The names,** Galaxy from the Greek, Via Lactea from the Latin, and our own Milky Way, all refer to the broad white band which traverses the entire circuit of the sky. The Chinese call it The Celestial River; the North American Indians, The Road of Souls.

574. **Its course** is in a great circle inclined about 63° to the equinoctial, which it crosses in the Eagle and in the

Unicorn. Beginning near the Eagle, we trace it north-east through Cassiopeia, to the right of Capella and Procyon, and to the left of Orion and Sirius; thence it passes through the Ship, and so beyond our horizon. Beyond Argo it divides into several fan-like branches, which unite again near the Cross. Beyond the Centaur, it divides into two streams, which flow side by side through the Scorpion, Sagittarius, and the Eagle, to the place of beginning.

575. **Its breadth and brightness.** — Near the Cross, where it is narrowest, it is only three or four degrees wide. At the Ship, and also at the Scorpion, it spreads over about twenty degrees of the sky. The brightest part in the north is near the Eagle and the Swan; the part in the south, between the Ship and the Altar, is yet more brilliant. Near this southern portion is a series of the brightest stars in the sky, beginning with Sirius, and including the beautiful stars of the Ship, the Cross, the Centaur, and the Scorpion. When this part of the sky rises above the southern horizon it brings a glow of light like that of the new moon.

576. **The telescope** resolves the galaxy into countless multitudes of stars, irregularly grouped. Star-clusters are very numerous, especially in the southern part. In some regions the stars are strewn very uniformly, in others a rapid succession of closely clustering, rich patches are separated by comparatively poor intervals, or, in some instances, by spaces quite dark and devoid of any star, even of the smallest telescopic magnitude.

A bright portion near the Cross surrounds a dark place of considerable breadth, and of pear-shaped form, called the *coal sack.* Similar spaces are found in the Scorpion, and in Ophiuchus. They are like windows opened through the dense wall of stars, through which we look forth into vast regions of starless space.

In many places the galaxy is so completely resolved by the telescope that the stars seem to shine out against a

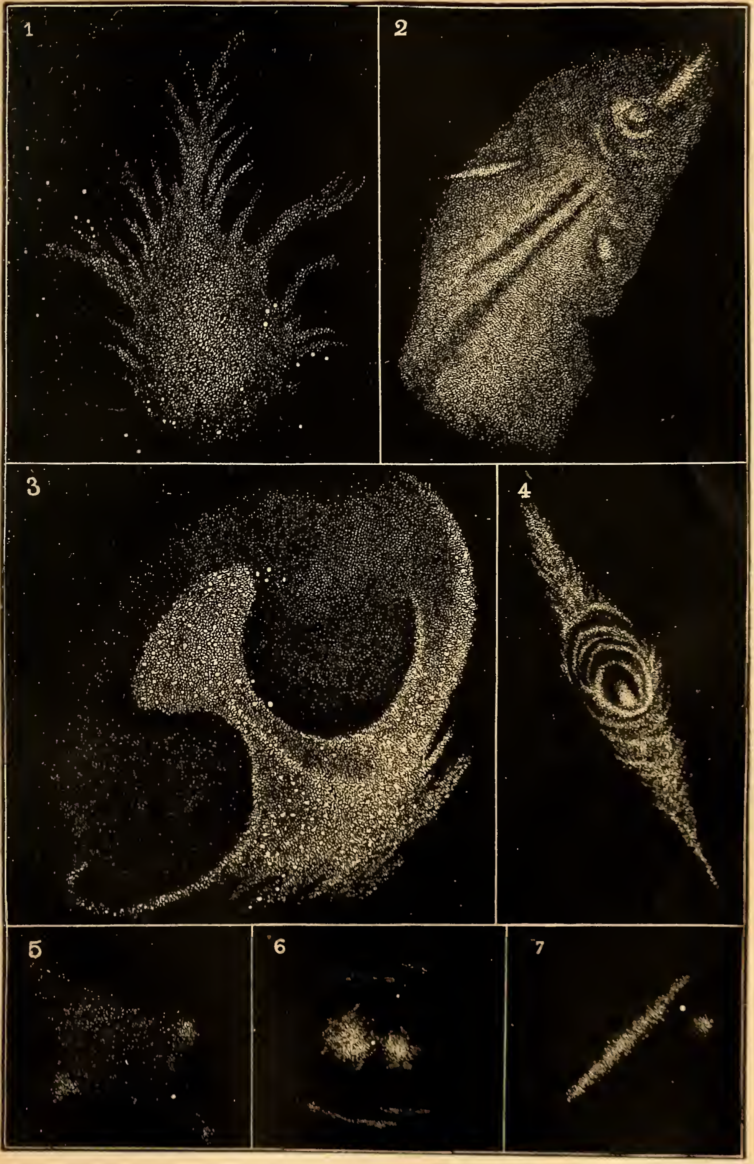

PLATE V.—1. Crab Nebula in Taurus. 2. Great Nebula in Andromeda. 3. Dumb-bell Nebula in Vulpecula. 4. Nebula in Leo. 5. Multiple Nebula in Nubecula Major. 6. Double Nebula. 7. Nebula in Coma Berenices.

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black ground; in others a faint white glimmer remains unresolved, showing that in these directions it has not yet been fathomed.

577. **The distribution of the stars.**—As the galaxy passes round the sky in nearly a great circle, the two points of the sky on either side, equidistant from that circle, may be called the *galactic poles*. Herschel I. made an elaborate investigation of the distribution of stars in the heavens by a system of "star-gauging." By counting the stars visible at once in the field of his telescope, and then comparing results from different parts of the sky, he found:

That the spaces near the galactic poles contained the smallest average number of stars;

That the average was generally the same at the same distance from the galactic poles;

That the averages increased with the distance, at first slowly, afterward much more rapidly;

That in the galaxy, the stars were crowded so thickly as to defy counting.

THEORIES OF THE GALAXY.

578. **Herschel's theory.**—That the sun is a member of an immense system of stars which form a layer or bed of circular shape, having but little thickness in comparison with its breadth. That this bed is split near its southern edge, the two flat surfaces diverging as if a wedge had been driven between them.

The figure shows a section of this supposed star-system, the sun being at *S*, not far from the split.

Herschel supposed that the stars are distributed pretty uniformly throughout this space. If so, a telescope pointed toward *B* would include in a single field but few stars, because the line of sight would soon pass out of the layer; if turned toward *E* more would be seen at once, and if toward *F*, a still larger number. Hence, he thought that his labors

of star-gauging would show, approximately, the shape and size of the galaxy, and the place of the sun within it.

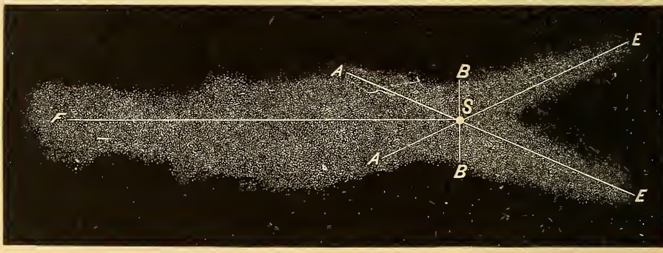

Fig. 173.

579. **This theory assumes** two positions which are believed to be untenable. These are:

1. That the stars are distributed uniformly.

2. That instruments are made which can fathom the farthest depths of space, and will enable us to count all the stars which exist in the direction in which we look.

But newer instruments of more delicate defining power continually reveal more stars, and Herschel himself finally admitted that the stars are greatly condensed in the immediate vicinity of the Milky Way.

580. **Mädler's theory.** — That the stars of the galaxy are arranged in an immense ring, or, perhaps, in several rings, one within another. To an observer within the system, the inner ring would seem to cover those beyond it.

That the sun is within the system, but nearer to the southern side; for this reason, the southern portion is most brilliant.

That the rings do not lie in the same plane; hence, the separation into two streams in the south, the divergence seeming necessarily greatest at the side nearest us.

581. **The dimensions** of the galaxy are, of course, only a subject of speculation. From the magnitude of the stars, Herschel concludes that the remote parts are at least 2300

times the average distance of fixed stars of the 1st magnitude. Light must occupy more than 10,000 years in coming from such a distance, or about 20,000 years in crossing from one side of this stellar system to the other. Herschel estimates the thickness of the stratum at about 80 times the distance of the nearest fixed star.

582. **Other galaxies.**—Herschel and Mädler agree that the sun is a member of this star-system. In the distant realms of space, this group of stars may present an appearance similar to that which we see in clusters already described. Herschel's scheme would indicate a planetary-nebula, Mädler's a ring-nebula.

It may be then that the resolvable nebulæ are other galaxies as large as our own, or even larger. How far away must the galaxy be removed from us that it may appear no larger than the ring-nebula in Lyra, which in Rosse's telescope seems less than an inch broad? The distance is beyond imagination's utmost reach. We can only say that it is to ordinary *stellar* distances, as they are to the most trivial measurements on our earth. The light of such a cluster, so remote, must be more than a *million of years* in coming to the earth.

Have we even then looked beyond the threshold of THE UNIVERSE?

MOTION OF THE SOLAR SYSTEM.

583. **Proper motion of the stars.**—Halley first conceived that even the fixed stars change their relative positions. He found that the ancient places of Sirius, Arcturus, and Aldebaran did not coincide with positions which he himself had determined. James Cassini ascertained that Arcturus had moved 5 minutes in 152 years, while neighboring stars had not been affected at all.

By carefully comparing and classifying all the proper motions then known, Herschel I. was led to infer that the

solar system was moving toward a point in the constellation Hercules, indicated by Rt. As. 17 h. 8 m., N. Dec. 25°; shown by a small circle in Plate X.

Other astronomers who have investigated this subject, agree in the general statement that the sun is moving towards a point in Hercules; as to the exact point they do not agree, but all place it in the small compass between R. A. 16 h. 12 m. to 17 h. 7 m., and N. Dec. 14° 26′ to 39° 54′.

It has also been asserted that "the velocity of the motion is such that the sun, with the whole cortege of bodies depending upon him, advances annually in the direction indicated, through a space equal to 1.623 radii of the terrestrial orbit," or 151 millions of miles. (W. Struvé.)

584. **The orbit of this motion.** — Continuing this investigation, Mädler concludes that the sun and all the members of the galactic system revolve about a center which he supposes to be Alcyone; the brightest star of the Pleiades. He estimates the sun's period of revolution to be 27 millions of years.

The mutual attractions of so many heavenly bodies is likely to produce a motion of revolution, but the center of such motion must be sought in the plane of the galaxy. The Pleiades lie considerably to the south of that plane. Argelander suggests that such a center may be sought with more propriety in the constellation Perseus.

Even if Alcyone were the center of the galactic system, it would by no means follow, as some have supposed, that that star is the center of the universe. The galactic system itself, can not be more than an individual member of a host of similar systems.

THE MAGELLANIC CLOUDS.

585. **Near the south pole** of the heavens are two masses of nebulous light which seem to be scattered fragments of the galaxy. Early voyagers in southern seas called

them "the Cape Clouds." Afterward they were named for Magellan, though by no right of discovery. They are known as the Great and the Small Cloud—Nubecula Major and Minor. The great cloud covers about 40 square degrees; the small is about one fourth as large. The region near the clouds is very poor in stars.

586. **In the telescope,** a structure is revealed which includes the Magellanic clouds among the wonders of the heavens. They contain a great number of single stars, from the 5th to the 11th magnitudes; very many star-clusters, irregular, oval, and globular; and, finally, nebulæ, separate, and grouped by twos and threes. In the great cloud are counted 580 single stars, 291 nebulæ, and 46 clusters.

These clouds seem to be miniatures of the celestial sphere, containing constellations, clusters of stars, and nebulous matter in different stages of condensation.

587. RECAPITULATION.

Fixed stars are classed in about 20 *magnitudes;* the first six, including about 6000 stars, are visible to the naked eye.

They are grouped in *constellations;* the stars in each are numbered according to *relative brightness.*

Stars are *self-luminous*, therefore *suns;* the spectroscope indicates that among their many elements are some *identical* with those found in our *sun*, and in the *earth*. Many far surpass our sun in magnitude and brilliancy.

The annual parallax of the fixed stars is *very small*, and for most is *imperceptible;* hence, they must be *very remote*. Light comes from the nearest in not less than 3.6 years; from some, in not less than 8000 years.

Stars vary in *brightness*. Some have *faded*, others have *vanished;* some have *grown more brilliant*, others *increase and diminish* with periodic regularity. They vary much in *color*, and sometimes *change color*.

Stars are *double*, *treble*, and *multiple*. *Optically double* stars, though very far apart, are so nearly in the same line with the earth, that the light of one is merged in that of the other.

Physically double or *multiple* stars show by rotation that some *physical connection* binds their components into a *system.* Some companion-stars have made an *entire revolution* about their primaries since they were discovered. The *dimensions of orbits* and *masses of primaries* have been computed.

Many stars are grouped in *clusters*, probably by some physical connection.

All *nebulæ* were thought to be *resolvable* into *star-clusters;* the spectroscope indicates that many are *irresolvable*—mere *cloudy*, *gaseous* masses. They present various shapes—*globular*, *elliptical*, *annular*, *spiral*—and they are often *exceedingly irregular.* Often one or more *nuclei* are seen. Some are *double*, and *multiple.*

The *galaxy* is a broad irregular belt of white light, which traverses the sky in nearly a great circle, and which is resolved by the telescope into an innumerable multitude of stars. Herschel believes that it is a great *stellar system*, of which the sun is a member; that it is disposed in a *lens-shaped* mass, the stars being distributed throughout with considerable uniformity. Mädler thinks the stars are arranged in one or more *rings*, not quite concentric.

Many fixed stars have a small *proper motion;* hence it appears that the solar system is *moving through space.* The motion is toward a point in the group Hercules, and is probably about a very remote center not yet known. Its rate is about 150 millions of miles per annum.

The *Magellanic clouds*, bright patches near the south pole of the sky, are resolved into *single stars*, *clusters*, and *nebulæ*,—entire stellar systems.

CHAPTER XXIII.

THE NEBULAR HYPOTHESIS.

588. Evidences of law in the harmonies of the solar system.—A general review of the bodies which compose the solar system, and of their varied movements, shows a remarkable agreement in many important items. Such coincidences can not spring from chance, but must result from the wise plans of the Great Architect who laid the foundations of the universe, and placed thereon the infinitely glorious systems of worlds, of which ours is an example. Nor can we think that God creates as men build, laboriously adding part to part, making one thing and fitting another thereto, until the whole is finished. Probably a single planet added to, or taken from, the solar system would so disturb the equal balance of forces which hold the others in their places as to entirely derange, if not to utterly destroy, the whole.

Wherever we question nature, we find that each of her varied processes, the simplest or the most involved, proceeds by virtue of some LAW, which secures a degree of uniformity in results, while the influence of peculiar circumstances, acting also in obedience to law, produces infinite variety within the limits of uniformity. We come to recognize among the sublimest attributes of Deity the wisdom which could devise, and the power which can enforce, laws which, by and through apparent confusion and conflict, develop out

of inert matter the wonderful mechanism of the Solar System and of the Stellar Universe.

589. The harmonies of the solar system.—Among them we mention:

1. All the planets, to the number of more than 200, revolve about the sun from west to east,* in orbits whose planes are nearly coincident with the plane of the sun's equator.

2. The sun rotates from west to east.

3. All the primary planets, so far as known, rotate from west to east.

4. The satellites, so far as known, revolve about their primaries in the direction of the planet's rotation. Except the satellites of Uranus and Neptune, they revolve from west to east.

5. The orbits of both planets and satellites have but slight eccentricity.

6. The densities of the planets increase in nearly the order of their approach to the sun. This is also true, so far as known, of the relative densities of satellites about their primaries.

590. The lessons of geology.—Geology teaches that the earth is probably a mass of molten material covered with a rigid, rocky crust but few miles thick. It teaches, farther, that the entire substance of the earth, including those elements which are melted with the greatest difficulty, was once fused. The heat which produced such fusion must have changed many substances, as water, compounds with carbon, and most metals, to the condition of vapor or gas. The appearance of the moon indicates that its nature is in this respect precisely like that of the earth; analogy leads us to suppose that all the planets and satellites are similarly constituted.

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* That is, *toward the left*, the observer being at the center of motion.

If we may conceive a degree of heat sufficient to fuse a part, and to vaporize the rest of the substances which compose the earth and the planets, there is nothing to forbid the conception of a degree of heat sufficient to change every known or supposed substance to a gaseous form.

591. **Heat and motion are different manifestations of the same force.**—The investigations of Rumford, Joule, Tyndall, and others, show:

1. That heat and motion, one force in two phases, are, like matter, indestructible.

2. That heat may be converted into motion and motion into heat.

The heat abstracted from the steam of the locomotive re-appears in the motion of the train. The motion of the cannon-ball, stopped by the iron armor of a ship, re-appears in the intense heat, both of the ball and of the plate struck—an amount of combined heat and force which has welded together two plates of the armor, at the place of the blow. The motion destroyed by friction explodes gunpowder, ignites wood, boils water, heats a rubbing axle red-hot.

Professor Tyndall asserts that if the earth were instantly stopped in its revolution about the sun, the quantity of motion which the globe possesses being transformed into heat is sufficient to flash at once all the material of the earth back to its original state of vapor. "Behold the heavens shall be rolled together as a scroll, and the elements shall melt with fervent heat."

THE HYPOTHESIS STATED.

592. **The nebular hypothesis** supposes that a portion of space now occupied by the solar system, and extending far beyond the remotest planet, was filled originally with matter so intensely heated as to be in a vaporous or nebulous condition. The attraction of gravitation between the particles, and the various forms of molecular attraction, though

existing, would be neutralized, in the main, by the active repulsion of the intense heat. Some heat would radiate from the surface of the nebulous mass into the spaces beyond. The cooling material would begin to contract upon its center, under the action of gravitation, and, as is the observed action of matter when moving toward a center, would begin to rotate. But the motion produced would be at the expense of more heat, which would cause more contraction and more rapid rotation. The equatorial portion would finally acquire motion enough to counteract, as a tangential force, the attraction of the central mass, acting as a radial force, and it would be left behind by the contracting center, forming a ring or zone. The same process repeated would throw off one zone after another, each being denser than the preceding, until the glowing central sun would remain, about which all these, its offspring, revolve.

As each zone was thrown off, or, rather, left behind, it must continue its motion of revolution about the central mass. The mutual attractions of the particles would cause them ultimately to unite in a spherical gaseous body, rotating upon its axis, and, by the same process which produced it, throwing off equatorial zones which become its satellites, revolving about it, as it revolves about the sun, and rotating upon their own axes.

593. **Peculiar results.**—The rings of Saturn appear to have retained the ring form, condensed laterally into their present very thin shape. The group of minor planets between Mars and Jupiter may be a ring which condensed about many nuclei, instead of one, none becoming powerful enough to absorb all the others. Leverrier has suggested the existence of a similar ring within the orbit of Mercury.

594. **The theory extended.** — The same process may have produced like results in other realms of the universe. The condensing globe of nebulous matter may have concentrated about two or more centers of internal attraction,

and thus systems of binary, ternary, or multiple suns may have been formed. Under such circumstances, these central masses must, as we know they do, revolve about their common center of gravity. One nebulous mass may have another bound to it by the universal law of mutual gravitation.

ANOMALIES EXPLAINED.

595.* **Retrogradation.**—When the parts of the condensing ring came together to form a planet, while this planet must retain the motion of revolution, impressed upon it as a motion of rotation when it was a part of the sun, the motion of rotation upon its own axis comes from the action of forces within itself, and may have gone to the right rather than to the left. But the motion of its satellites must conform to its rotation. Hence, the retrograde motions of the satellites of Uranus and of Neptune offer no argument against the theory, unless it shall be found that the planets themselves rotate toward the left.

596. **Comets and meteorites.**—In this concentration of the matter of the universe about centers, many portions would be left in the spaces between the spheres of contraction, and would be joined to none. Such a portion would remain by itself, undergoing, doubtless, like action, until some solar system in its motion through space should come into its vicinity, bringing it within the influence of the new attraction. These isolated masses would join the larger systems as comets, or as streams of meteoric substances. Some comets may have come from fragments of nebulous rings, portions which did not coalesce with the rest, but were drawn aside by the attraction of the central mass, or of other masses already condensed beyond them.

597. **Plateau's experiment.** — A mass of oil is suspended in alcohol, diluted to exactly the density of the oil;

it readily arranges itself about a central wire, which may rotate as an axis, carrying the oil with it.

The oil, being freed from the action of gravitation, assumes the form of a perfect sphere.

When made to rotate, this globe becomes flattened at the poles; under more rapid rotation, the globe becomes a ring in the equatorial plane, which separates into small masses that at once assume globular forms, and often take, at the instant of formation, a motion of rotation on their own axes, usually in the direction of the rotating ring.

A ring is sometimes formed while part of the original globe remains on the axis.

Here we have most of the phenomena supposed by the nebular hypothesis, reproduced on a small scale.

598. **The nebulæ.** — To the hypothesis, it has been strongly objected that, if systems are developed in this manner, we might expect to find examples in all stages of progress among the innumerable objects in the sky; and that the facts of astronomy do not warrant the conclusions, under the assumption that all nebulæ are resolvable by sufficient instrumental power. But some nebulæ have never been resolved, and the spectroscope indicates that some are composed of *gaseous matter alone.* Some of the best known have changed both in form and brightness. The forms of globular, annular, spiral, and irregular nebulæ at once suggest themselves as giving color to the hypothesis.

599. The nebular hypothesis was advanced by Herschel I. in 1783, and was elaborately discussed by La Place. It has been the field of much astronomical, geological, and religious controversy. After each apparent defeat, it seems to have gained fresh vigor from new discoveries, and it is now very generally received by scientific men.

Yet it remains but a theory, to give place instantly to any other which shall more completely or more simply explain all the phenomena of the universe.

CHAPTER XXIV.

THE CONSTELLATIONS.

600. **Celestial globes and star maps** are often covered with figures of men, animals, and monsters—imaginary forms which have descended from the ancient mythology and astrology. In a few cases, a fanciful resemblance may be traced; in most, the outlines of the map confuse the learner, because he can find nothing of the sort in the sky. "The constellations seem to have been almost purposely named and delineated to cause as much confusion and inconvenience as possible. Innumerable snakes twine through long and contorted areas of the heavens, where no memory can follow them; bears, lions, and fishes, large and small, northern and southern, confuse all nomenclature."*

In our star maps, the monsters are, therefore, omitted, and the sky is divided into districts, most of which retain their classical names. The learner will most easily find them by studying the simple geometrical figures which are formed by prominent stars.

601. **The Maps.**—The circumpolar map, Plate VI., represents so much of the sky as is included within the circle of perpetual apparition for an observer at 40° N. Lat. The horizon lines are indicated, for eight months of the year, at 8 o'clock, P. M.; by turning the map, it is easily rectified for any other hour or month. When studying it, the learner should face the north.

* J. F. W. Herschel.

Each of the equatorial maps, Plates VII.–XII., shows the positions of the stars which are within 30° of the meridian at the time specified, and which lie between the horizon and the circle of perpetual apparition. This space is 100° from south to north, and, therefore, extends 10° beyond the zenith; it is 60°, or 4 hours, wide; the six maps complete the circuit of the sky.

602. To use the maps.—The learner should find the place of his meridian, and be able to trace it readily from south to north. The zenith found, it will not be difficult to fix a point on the meridian, 50° above the horizon, as the intersection of the equinoctial, and to trace the equinoctial to the east and west points of the horizon. These lines form the foundation of the work, and are represented by the vertical and horizontal lines which cross the center of the map. Face the south, and raise the map until the equinoctial line is opposite the equinoctial in the sky; the constellations will be found in their places on the day and hour mentioned.

Nothing will supply the place of a few hours' work in the open air, month by month, as the seasons pass. A little patience with the maps,—alone, or with help from another who knows the stars,—will make any person thoroughly familiar with the sky.

Two who study together will get much help from a very simple contrivance. Two light, straight rods are placed exactly parallel, and fastened to two cross-bars; while the teacher looks along one rod, which he points to any particular star, the pupil looking along the other rod will readily identify the star.

January 20, 8 p. m.

603. The circumpolar map. Plate VI.—The most notable constellation is *Ursa Major*, the Great Bear. The seven bright stars of this group, east of the meridian, are

familiarly known as the *great dipper*. The pair of stars which form the upper side of the dipper, or that farthest from the handle, are called *the pointers*, because a line drawn through them passes very near the pole star. They are 5° apart, and hence are convenient to measure distances by. The star at the bend of the handle is Mizar; near it is a small star, Alcor, which has been considered a test of keen vision; the Arabs called it Saidak, or *the proof* (541).

Guided by the pointers, we easily find Polaris, a star of the 2d mag.; no star of equal magnitude is nearer to it than the pointers. From Polaris a line of small stars curves downward to the right and meets the upper of a pair of stars of 3d mag.; with a faint star at the lower corner, these form a second or *little dipper*. The group is *Ursa Minor*.

Draco nearly surrounds Ursa Minor. The head is at two bright stars near the horizon, about 15° west of the meridian; the body coils through the space between the two Bears.

From Mizar draw a line through Polaris; at about the same distance on the opposite side are five rather bright stars, which form a rude, flattened letter M. They are the principal stars of *Cassiopeia*. Between Cassiopeia and Draco is *Cèpheus*, while the large space void of bright stars on the opposite side of the pole is occupied by the *Camelopard* and the *Lynx*.

604. The equatorial map. Plate VII.—Plate XI. is on the west; Plate VIII. on the east. *Taurus* is in the center of the field, just north of the equinoctial. West of the meridian is the beautiful cluster of the *Pleiades*; six may be counted on a clear night, the brightest being Alcyone, of the 3d mag. (584). East of the meridian and a little lower in altitude are the *Hyades*, often called the *great A*; at present, the stars are rather in the position of a *V*. Aldebaran, a red star of the 1st mag., forms one foot of the letter; it is also the *bull's eye*.

South-east from Taurus is *Orion*, the most beautiful group in our sky, and one of the few in which the outline of a man may be traced. Just south of the equinoctial, three stars of the 3d mag. form an oblique line, 3° in length. They are the *girdle;* a small star which marks a right angle with the lower end of the girdle is in the *sword.* Above, two bright stars, Betelgeuze the eastern and Bellatrix the western, form the shoulders, while a small triangle of three stars marks the head. Below the girdle, Rigel, of 1st mag., marks the right foot; a smaller star, east of Rigel and opposite Bellatrix, shows the left knee, on which the man is kneeling as he fights the bull.

A small triangle below Rigel, and a trapezoid south of the girdle, mark the constellation *Lepus.*

West of the Pleiades, the single bright star is Alpha Arietis, or simply Arietis; it marks the Tropic of Cancer and the second hour-circle. South of Arietis and west of the girdle of Orion is the star Mira (547), in the constellation *Cetus.* Mira and the girdle are about equally distant from the Pleiades, and the three form a right angle at the Pleiades. Another bright star of Cetus lies in a line between Mira and Aldebaran.

The space south of Taurus, between Orion and Lepus on the east and Cetus on the west, is occupied by *Eridanus*, with few notable stars.

North of Aldebaran and near the zenith is the beautiful blue star Capella, of the 1st mag., in *Auriga;* it is attended by a star of 2d mag., about 5° to the east. Midway between Capella and Bellatrix, a bright star is referred indifferently to Auriga or to Taurus.

Perseus lies west of Auriga, its brightest star, Alpha Persei, being nearly due west of Capella, and but little nearer the zenith; a line from Rigel through Aldebaran meets this star. Algol (546) is south-west from Alpha Persei, nearly in a line with Arietis, which is equally distant from Algol and the Pleiades.

605. **In the east.**—A line from Aldebaran through Bellatrix meets, in the south-east, Sirius, the brightest star of the sky. Farther toward the east, Procyon makes an equilateral triangle with Sirius and Betelgeuze. Near the prime vertical and about midway to the zenith are the two bright stars, Castor and Pollux, while farther toward the north Regulus and the sickle are just visible in the haze above the eastern horizon.

606. **In the west.**—Four large stars form a nearly square figure whose diagonal is near the prime vertical; the largest is Alpheratz of *Andromeda.* The square is the *square of Pegasus.* Two prominent stars between Alpheratz and the zenith, with Algol and the square, form a figure much like the great dipper, but larger; the handle may end with Algol or with Alpha Persei.

In the north-west, Deneb of *Cygnus* is just setting.

The galaxy crosses the sky in a great circle from north-west to south-east, passing Deneb, Cassiopeia, Perseus, and between Taurus, Orion, and Sirius on the one side, and Capella and Procyon on the other.

MARCH 21, 8 P. M.

607. **The equatorial map. Plate VIII.**—The central star of the map is Procyon of *Canis Minor;* it is about 5° west of the meridian and north of the equinoctial. North of Canis Minor, the zodiacal constellation *Gemini* is marked by the two bright stars Castor and Pollux, Castor being the highest and brightest. Gemini meets Taurus and Orion near the western margin of the map, and *Cancer* at the meridian. Cancer contains no bright stars, but about equally distant from Procyon, Castor, and Regulus is a remarkable cluster of stars, called *Præsepe* (561), the manger, and sometimes the *Beehive.*

This map has been extended a little toward the east in order that it may include Regulus, the brightest star of *Leo,*

which lies on the ecliptic and very near the tenth hour-circle. In this constellation, six stars form the rude outline of a *sickle*, Regulus being at the end of the handle; they also show the *head* of the Lion, Regulus being the *heart*.

South-west from Procyon is the beautiful constellation *Canis Major*, studded with bright stars. Sirius, with a star about 5° west of it, and two others about equally distant from each other, but farther south, form an oblique parallelogram, inclined toward Orion.

The space between the two Dogs, Gemini and Orion, is occupied by *Monoceros*. East of Monoceros, and south of Cancer, is a part of *Hydra*, whose only bright star is Cor Hydræ, south of Regulus. *Argo* is in the south, near the horizon.

608. In the east.—Arcturus, the bright star of *Boötes*, has just risen; a line which joins it with Polaris passes between the last two stars in the handle of the Dipper. Denebola, in *Leo*, is nearly in a line which joins Arcturus and Regulus.

In the west.—Capella has passed to the north of the prime vertical, and is about 30° from the zenith. The Pleiades are midway between Capella and the horizon. Orion, Aldebaran, and Sirius are bright in the south-west. Arietis is near the horizon in the north-west; Algol is in the great arc of bright stars which begins at Arietis, sweeps through Capella and its comrade, Castor and Pollux, and ends with Procyon or Sirius.

The galaxy may be traced in a great circle from the north to the south, crossing the prime vertical in the west about 50° above the horizon.

MAY 21, 8 P. M.

609. The equatorial map. Plate IX. — *Leo*, the brightest constellation, has just passed the meridian, and

occupies the western central part of the map; Denebola, the most eastern star of the group, is about 30° from the zenith, and very near the meridian. Two smaller stars to the westward of Denebola form a right-angled triangle with it. Regulus marks the ecliptic and the tenth hour-circle.

South-east from Leo, and on either side of both equinoctial and ecliptic, stretches the constellation *Virgo.* Its brightest star, Spica, of 1st mag., is very near the ecliptic; it forms a large equilateral triangle with Denebola and Arcturus.

South-west from Spica, and nearly on the meridian, four stars of medium brightness, in a trapezium, mark the *Crow; Crater* is west of the Crow, and south of Leo; south of Virgo, Corvus, Crater, and Leo, sweeps the long trail of *Hydra*, whose only bright star, Cor Hydræ, is south-west of Regulus.

Between Leo and the Bear a few small stars mark the place of *Leo Minor.* A cluster of stars called *Berenice's Hair* lies west of Arcturus and north-east of Denebola. *Canes Venatici* occupy the remaining space to the Dipper; the principal star is Cor Caroli, of 3d mag.

610. In the east.—Arcturus is most prominent directly south-east from the Bear. Arcturus and Spica form the base of a large isosceles triangle, whose vertex is in a bright star of *Scorpio*, just risen in the south-east. Below the head of Draco, Vega, the bright star of *Lyra*, is well up in the north-east. Between Vega and Arcturus glistens the circlet of the *Northern Crown*, on the prime vertical, about half way to the zenith. A little south of east, the long line of stars which forms the *Serpent* stands perpendicular to the horizon.

In the west.—The Twins are midway between the Dipper and the horizon; in the north-west, Capella and its mate have about the same altitude. South-west from the Twins, Procyon is nearly set.

The galaxy lies in a great circle just above the horizon, from the west through the north to the east; it is usually invisible, because of the haze.

JULY 22, 8 P. M.

611. The equatorial map. Plate X.—The brightest constellation is *Scorpio*, midway between the equinoctial and the horizon. Its largest star, Antares, of 1st mag., is about 5° east of the meridian; on the meridian is a star of 2d mag., and two others of 3d mag. are a little lower, to the west; the four form a figure like a boy's kite, to which a line of stars below Antares forms the tail. The Tropic of Capricorn and the ecliptic pass through the kite above Antares.

Between Scorpio and Virgo is *Libra*, shown by two stars of 3d mag., which mark the scales; they are about equally distant from a line which joins Antares and Spica.

North-east of Scorpio is *Ophiuchus*, covering a space, not well supplied with bright stars, more than 40° in width; two stars of 3d mag., about 10° apart, lie east of Antares; Alpha Ophiuchi is nearly on the line from Antares to Vega, and 12° north of the equinoctial.

The center of the map is occupied by the *Head of Serpens*, the brightest star being about 7° north of the equinoctial and west of the meridian. Two stars below and three above form an outline like the crook of a shepherd's staff.

North of Serpens is the *Northern Crown*, a semicircle of six stars; the central and brightest is called the *Gem*.

West of Serpens and the Crown is *Boötes*, extending from Virgo to Draco. The principal star is Arcturus, a red star of 1st mag., about 30° from the zenith in the south-west. Four stars west of the Crown form a cross; with Arcturus and two to the south-east, an irregular figure 8.

East of Serpens and Corona, *Hercules* occupies the space between Ophiuchus and Draco. The brightest star, of 2d mag., lies between the Gem of Corona and Alpha Ophiuchi; it forms an isoscles triangle with the Gem and the bright star of the Serpent. A flattened arc of small stars extends from this star beyond the zenith. The small circle on the

map marks the point toward which the solar system is moving (583).

612. In the east.—Vega is east of the zenith. Farther north, in the Milky Way, about 45° from the horizon, is Deneb, the chief star of Cygnus. South-east, and also in the galaxy, is Altair, of the *Eagle*, easily recognized by its two bright attendants in a vertical line. Near the horizon, the bright stars of *Pegasus* appear in the north-east.

In the west.—Spica is low in the south-west, and Regulus is near the western horizon.

The galaxy passes from north to south, crossing the prime vertical about midway to the zenith.

SEPTEMBER 23, 8 P. M.

613. The equatorial map. Plate XI.—The central figure is Aquila; its brightest star, Altair, of 1st mag., being west of the meridian and north of the equinoctial; a star of 3d mag. is near it on either side; the line of the three prolonged meets Vega west of the zenith.

Sagittarius lies south of Aquila; four small stars in a trapezoid, with another to the west, form what is sometimes called the "*milk dipper;*" the handle has fallen into the Milky Way.

Capricornus is east of Sagittarius and south-east of Aquila; two small stars near the meridian are the only ones of note. North-east of Capricornus is *Aquarius*.

North-east of Altair, four small stars in a trapezoid mark the *Dolphin*.

In the zenith we find *Cygnus;* its brightest star is Deneb, of 1st mag., in the body of the bird. The head is at a star of 2d mag., almost in line with Vega and Altair; four stars of 3d mag., which form a line across the body between the head and Deneb, mark the wings.

Lyra occupies the space between Cygnus and Hercules. Vega is the bright star nearest the zenith.

614. **In the east.**—The great square of Pegasus is on the prime vertical, midway to the zenith. Arietis and Algol have risen in the north-east; Capella is peering through the mists still farther north.

In the west.—Arcturus hastens to his setting; the Crown is on the prime vertical; the Serpent is south-west of the Crown, and south of Arcturus.

The galaxy crosses from north-east to south-west through the zenith.

NOVEMBER 22, 8 P. M.

615. **The equinoctial map. Plate XII.**—The central figure is the square of *Pegasus*, the eastern side being on the meridian. Although called the square of Pegasus, the brightest star is Alpheratz, of *Andromeda.* Two stars to the north-east, in line with Alpheratz, also belong to Andromeda.

East of Pegasus is the constellation *Pisces*, of the zodiac, without any notable stars. Directly south of Alpheratz and its companion in the square is the Vernal Equinox.

Aquarius lies south-west of Pisces and Pegasus; its brightest stars are a pair of 3d mag., near the equinoctial, on the western side of the map.

South of Aquarius and near the horizon, we find a star of 1st mag., Fomalhaut, of *Piscis Australis.*

East of Aquarius and south of Pisces is *Cetus;* a star of 2d mag., about 10° east of the meridian, marks the tail of the monster; farther east, five stars make a rude sickle in the body; still farther east, two stars of 2d mag., one of which is Mira, form the head.

616. **In the east.**—Orion's belt appears at the horizon, preceded by Betelgeuze and Bellatrix, and followed soon by Rigel. The Pleiades are midway to the zenith; Aldebaran is between the Pleiades and the Girdle. Perseus lies between the Pleiades and the zenith. In the north-east, Capella and

its comrade are about 30° above the horizon; and below them, just rising, are the Twins.

In the west.—Cygnus is on the prime vertical, opposite Perseus; Aquila with Altair is south of west, about 20° from the horizon.

The galaxy crosses from west to east through the zenith.

No season of the year gives at this hour of the night a finer display of stars. Except Canis Major, Scorpio, and Leo, all the brightest constellations which ever appear above our horizon are visible, with the largest proportion of bright stars.

APPENDIX.

I. **The meridian altitude of the equinoctial = the co-latitude of the observer** (51). Let *HPO* be the visible half of the observer's meridian; *P*, the pole; *E*, the intersection of the meridian and the equinoctial; *EO* equals the meridian altitude of the equinoctial; *PH*, the latitude of the observer (39). From the semi-circumference *HZO*, take the quadrant *PE*; the remaining arcs, *PH* and *EO*, are together equal to a quadrant; hence, either of them is the complement of the other (Geom. 207, 94).

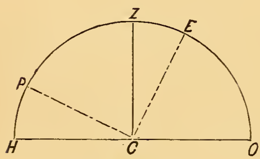

Fig. 174.

II. **The sextant** (115). When the index-arm *AO* is at zero, at *N*, the *index-mirror* *A* is parallel to the *horizon-glass* *B*. Let the index-arm be so moved that a ray from the star *S* is reflected to the horizon-glass, and thence to the eye at *K*, in coincidence with a ray *HK* from a second object. The angle *OAN*, traversed by the index-arm, is half the angle *SCH*, between the two bodies.

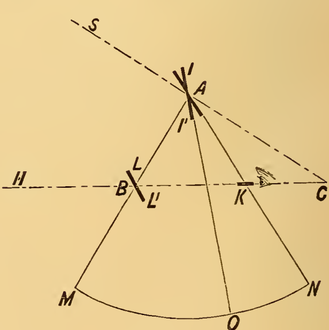

Fig. 175.

(Art. 72) $SAI = BAO \therefore SAB = 180° - 2BAO;$
$LBA = L'BC \therefore ABC = 180° - 2LBA;$
(Geom. 261) $SCH = SAB - ABC =$
$180° - 2BAO - (180° - 2LBA) = 2LBA - 2BAO;$
(Geom. 125) $LBA = BAN.$
$\therefore \frac{1}{2}SCH = BAN - BAO = OAN$, Q. E. D.

III. **The sun's declination** (131) may be sought in the nautical almanac, or is found as follows:

In the spherical triangle ABC, right-angled at C, let A be the vernal equinox, and B the place of the sun. AB, part of the ecliptic, is the sun's longitude (119); AC, part of the equinoctial, is the sun's right ascension (35); BC is the declination required. A is the obliquity of the ecliptic, 23° 27′ 14″ (58). The sun's longitude may be computed from his motion, or may be observed with the transit and clock. Then (Geom. 882),

Fig. 176.

$$\sin C : \sin A :: \sin AB : \sin BC.$$

IV. **The radius vector describes equal areas in equal times** (204). In Fig. 69, take the first two sections from A to G, and draw FO. The triangles AOD and DOF have equal bases, AD and DF, and their vertices are at the same point, O; hence (Geom. 388), they are equivalent. The triangles DOF and DOG have the common base DO, and their vertices are in the line FG, parallel to the base; hence, they are equivalent. That is,

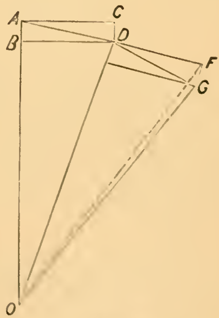

Fig. 177.

$$AOD = DOF = DOG.$$

Similarly,

$AOD = DOG = GOK = KON = NOR$, etc. (Fig. 69.)

V. **The precession of the equinoxes** (229). The equatorial radius is longer than the polar radius by about 13 miles (154). We may consider that the earth is a sphere surrounded by a belt of matter which is 13 miles thick at the equator, and diminishes to nothing at the pole. We may call it the *equatorial belt*. The precession of the equinoxes is caused by the unequal attraction of the sun and moon upon different parts of this belt.

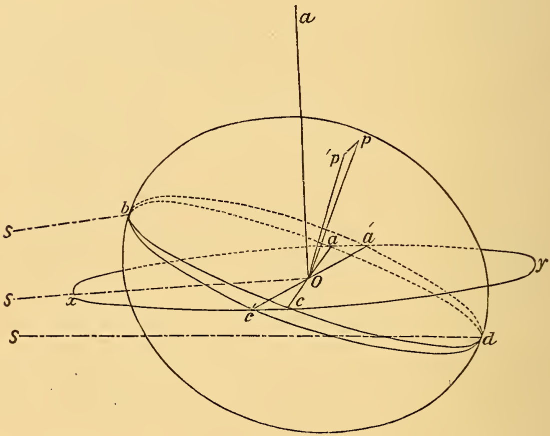

Fig. 178.

Let *abcd* represent the earth's equator, and *axcy* the plane of the ecliptic. Let us consider the effect of the sun's attraction upon two particles, *b* and *d*, at opposite sides of this belt; the diameter which joins them is equivalent to a rigid bar, or lever, whose fulcrum is at *o*, the center of the earth.

When the earth is at the equinoxes, the sun is in the direction of the line *ac;* the particles *b* and *d*, are equally distant from the sun, and are, therefore, equally attracted.

When the earth is at the solstice, the sun is in the line *ox;* *b* is nearer the sun than *d*, and is, therefore, more strongly

attracted; the tendency of the sun's force is to draw the bar *bod* into the line *xoy*. But the bar has with the earth a motion of rotation about *o* in the plane *abcd;* this force of rotation unmodified would keep it always in that plane, and the particle *b* would fall on *c*. The sun's attraction draws *b* a little aside from the path it would follow if influenced only by rotation, and it falls upon *c*′, a little backward, or westward of *c*. While *b*, in its journey from *a* to *c*, has been thus drawn aside, *d*, at the other end of the bar, being attracted less strongly by the sun, has in like manner been forced out of the path which rotation alone would have marked for it, and it falls upon *a*′, a little behind *a*. The result is that the diameter *bod* does not come back to the place *aoc*, but is twisted about into a new position *a*′*oc*′. What is true of the two particles *b* and *d*, is true of all other particles in the equatorial belt, since all in succession are similarly affected by the sun's attraction. Hence follows a constant westward motion of the line which joins the points where the ecliptic and the equator meet, or the equinoxes.

As the particles in the equator ascend from *a*, the angle which they make with the ecliptic is diminished, while as they descend toward *c* their angle is increased; the two effects counterbalance, leaving the angle between the two planes unchanged, but causing a slight rolling motion of one on the other.

Thus far we have confined our thoughts to the influence of the sun's attraction upon the equatorial belt. But any external force which is out of the plane of that belt will have a similar effect. The influence of the moon is even greater than that of the sun in causing precession, because the moon is so much nearer the earth.

As the equinoctial has this slow rolling motion upon the ecliptic, it is evident that the axis of the earth has a motion of revolution about the axis of the ecliptic. The pole of the heavens is moving about the ecliptic pole at a distance of about 23° 28′. The time of a complete revolution is found

by dividing 360° by 50″, the amount of annual precession; it is about 26,000 years. During that time the pole will move through the constellations Cepheus, the Swan, the Lyre, Hercules, and Draco, and will finally return to its present place.

VI. **Nutation.**—The plane of the moon's orbit makes an angle of about 5° (358) with the ecliptic. The line of the nodes (359) revolves once in about 19 years, changing the

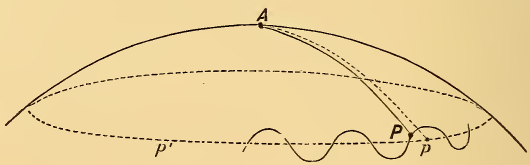

Fig. 179.

moon's extreme declination from 28½°, when its precessional effect is greatest, to 18½°, when that effect is least. Hence, the pole of the equinoctial is drawn from the pole of the ecliptic, alternately less and more than the average, and describes, not an exact circle, but a waved line, as in the diagram. This waved motion of the pole is called *nutation.* Its effect is to cause a slight displacement of the stars, alternately increasing and diminishing their declination. The effect of precession is to increase their right ascension regularly.

VII. **Ecliptic limits. Of latitude** (373). Let *S* represent the sun, *E* the earth; *M* the moon; *SEA* marks the plane of the ecliptic. Draw *DA* tangent to the surfaces of the sun and earth. It is evident that the surface of the moon must come within this line in order that an eclipse of either sun or moon may occur. *HEM* is the angular distance of the center of the moon from the ecliptic, or the *limit of latitude*, at which a solar eclipse may occur; *IEN* the limit of latitude of a lunar eclipse.

SED is the angle of the		sun's apparent radius;	
BEM, or *CEN*,	"	moon's	"
EDK	"	sun's horizontal parallax;	
EBK	"	moon's	"

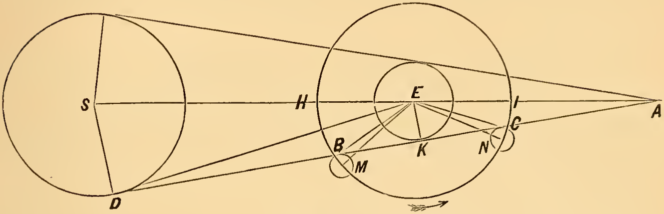

Fig. 180.

From the figure, $HEM = SED + BEM + DEB$.
Because EBK is exterior to the triangle DBE,
$DEB = EBK - EDB$ (Geom., 261).
Substituting, $HEM = SED + BEM + EBK - EDB$.

Translating: *The limit of latitude for a solar eclipse equals the sum of the solar and lunar apparent radii, plus the difference between the solar and lunar horizontal parallaxes.*

Omit the solar parallax, because it is very small, and substitute the largest possible values of the other quantities. $HEM = 16\frac{1}{4}' + 16\frac{3}{4}' + 62' = 95'$; if the moon's latitude at inferior conjunction be so much, an eclipse *may* occur. Again, $15\frac{3}{4}' + 14\frac{3}{4}' + 53\frac{1}{2}' = 84'$: if the latitude be so much, an eclipse *must* occur.

Again, from the figure, $IEN = CEN + CEA$.
Because ECK is exterior to the triangle ACE,
$CEA = ECK - EAC$.
Because SED is exterior to the triangle EAD,
$EAC = SED - EDK$.
Substituting, first, $CEA = ECK - SED + EDK$.
Next, $IEN = CEN + ECK - SED + EDK$.

Translating: *The limit of latitude for a lunar eclipse equals the moon's apparent radius, minus the sun's apparent radius, plus the sum of the solar and lunar horizontal parallaxes.*

Applying values as before, $16\frac{3}{4}' - 15\frac{3}{4}' + 62' = 63'$, the limit when greatest; $14\frac{3}{4}' - 16\frac{1}{4}' + 53\frac{1}{2}' = 52'$, the limit when least.

VIII. **Ecliptic limits. Of longitude.** — From the limits in latitude those in longitude are readily found. In the right-angled triangle *ABN*, the angle *N* is the inclination of the moon's path to the ecliptic, therefore $= 5° 9'$ (336); the side *AB* is the limit of latitude, as found above, and the side *NB* is required. The solar ecliptic limit is about 17° (15° 20′ to 18° 36′); the lunar ecliptic limit, about 12° (9° 23′ to 12° 24′).

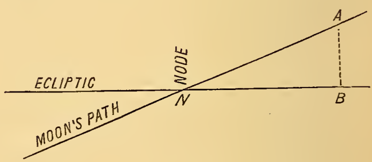

Fig. 181.

IX. **Airy's experiment** (171). Spheres of like density are to each other as the cubes of their radii (Geom. 806); spheres of unlike density are as the products of their respective densities into the cubes of their radii. Hence (158),

$$G : G' :: \frac{dR^3}{R^2} : \frac{d'R'^3}{R'^2} :: dR : d'R'.$$

Even if R' is less than R, d' may be enough larger than d to make $d'R' > dR$, and, therefore, $G' > G$.

TABLES.

TABLE I.—EQUATION OF TIME.

	5	10	15	20	25	30
	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.
January	**5 50**	**7 56**	**9 49**	**11 25**	**12 41**	**13 37**
February	**14 16**	**14 28**	**14 20**	**13 55**	**13 12**	**12 15**
March	**12 35**	**10 21**	**8 58**	**7 30**	**5 59**	**4 26**
April	**2 38**	**1 14**	4	1 12	2 10	2 57
May	3 29	3 48	3 52	3 41	3 18	2 43
June	1 46	50	**13**	**1 18**	**2 22**	**3 22**
July	**4 18**	**5 05**	**5 41**	**6 05**	**6 14**	**6 09**
August	**5 43**	**5 05**	**4 13**	**3 08**	**1 50**	**23**
September	1 32	3 13	4 58	6 44	8 28	10 08
October	11 40	13 03	14 14	15 11	15 52	16 15
November	16 17	15 55	15 12	14 08	12 45	11 02
December	9 03	6 51	4 28	2 01	**28**	**2 55**

Full-faced figures show that the clock is *faster* than the sun.

Plain figures show that the clock is *slower* than the sun.

The equation is given in minutes and seconds for each fifth day. It is found for intervening days thus: Suppose the equation is sought for Feb. 12. The difference between the tabular numbers for Feb. 10 and 15 is (14 28 — 14 20) 8 seconds; $\frac{2}{5}$ of 8 sec. is 3 + sec.; 14 28 — 3 = 14 25, the equation sought. Observe the different treatment required for, say, July 8, or April 14.

The table is for the year 1885; but will not differ materially for several subsequent years.

TABLE II.

To find the day of the week on which the first day of any month falls, from 1753 to 1905.

USE OF THE TABLE.

In the table on the following page, look for any year; below, in the same column, will be found the day of the week on which each month of that year begins. Thus, in the year 1753, 1759, 1770, etc., January begins on Monday, February on Thursday, March on Thursday, April on Sunday, etc.

On leap years, marked by full-faced type, the months from March forward begin one day later than the day found in the table. Thus, 1776 being leap-year, March 1 fell on Friday instead of on Thursday.

Days of the month which fall on the same day of the week:

1, 8, 15, 22, 29.	4, 11, 18, 25.
2, 9, 16, 23, 30.	5, 12, 19, 26.
3, 10, 17, 24, 31.	6, 13, 20, 27.
7, 14, 21, 28.	

Example.—The battle of Waterloo was fought on the 18th of June, 1815. What was the day of the week?

Solution.—The year 1815 is found in the last column, and is not leap-lear. The first of June fell on Thursday, as did also the 8th and 15th, and the 18th was Sunday.

Example.—On what day of the week will Christmas fall in 1896?

Solution.—1896 will be leap-year, and is found in the third column. The 1st and the 22d fall on Tuesday and the 25th on Friday.

	D.	H.	M.	S.
Mean Solar Day, ...		24		
Sidereal Day, ...		23	56	4.09
Mean Lunar Day, ...		24	54	
Mean Sidereal Year, ...	365	6	9	9.6
Mean Solar or Tropical Year, . .	365	5	48	46.
Mean Anomalistic Year, . . .	365	6	13	49.3

	1753	1754	1755	**1756**		1757	1758
	1759	**60**		61	1762	63	**64**
		65	66	67	**68**		69
	1770	71	**72**		73	74	75
	1776		77	78	79	**80**	
	1781	82	83	**84**		85	86
	1787	**88**		89	90	91	**92**
		93	94	95	**96**		97
	1798	99	1800	1801	1802	1803	**1804**
		1805	6	7	**8**		9
	1810	11	**12**		13	14	15
	1816		17	18	19	**20**	
	1821	22	23	**24**		25	26
	1827	**28**		29	30	31	**32**
		33	34	35	**36**		37
	1838	39	**40**		41	42	43
	1844		45	46	47	**48**	
	1849	50	51	**52**		53	54
	1855	**56**		57	58	59	**60**
		61	62	63	**64**		65
	1866	67	**68**		69	70	71
	1872		73	74	75	**76**	
	1877	78	79	**80**		81	82
	1883	**84**		85	86	87	**88**
		89	90	91	**92**		93
	1894	95	**96**		97	98	99
	1900	1901	1902	1903	**1904**		1905
Jan.	M.	Tu.	W.	Th.	F.	Sa.	Su.
Feb.	Th.	F.	Sa.	Su.	M.	Tu.	W.
Mar.	Th.	F.	Sa.	Su.	M.	Tu.	W.
April	Su.	M.	Tu.	W.	Th.	F.	Sa.
May	Tu.	W.	Th.	F.	Sa.	Su.	M.
June	F.	Sa.	Su.	M.	Tu.	W.	Th.
July	Su.	M.	Tu.	W.	Th.	F.	Sa.
Aug.	W.	Th.	F.	Sa.	Su.	M.	Tu.
Sept.	Sa.	Su.	M.	Tu.	W.	Th.	F.
Oct.	M.	Tu.	W.	Th.	F.	Sa.	Su.
Nov.	Th.	F.	Sa.	Su.	M.	Tu.	W.
Dec.	Sa.	Su.	M.	Tu.	W.	Th.	F.

PARALLAX 8.8″ TABLE III.—ELEMENTS OF THE PLANETS. FOR 1850.

NAME.	SIGN.	DISTANCE FROM THE SUN. EARTH'S RADIUS VECTOR = 1. GREATEST.	LEAST.	MEAN.	MEAN DIST. MILES.	ECCENTRICITY.	INCLINATION TO PLANE OF ECLIPTIC.	ORBIT. SYNODIC REVOLUTION MEAN SOLAR DAYS.	SIDEREAL REVOLUTION. Days.	Years.	MEAN HOURLY MOTION IN ORBIT.	MEAN DAILY MOTION IN LONGITUDE.
							° ′ ″		Days.	Years.	Miles.	° ′ ″
Mercury.	☿	.466692	.307504	.387099	35,955,790	.20560	7 0 7.7	115.877	87.969	0.240	107,105	4 5 33
Venus.	♀	.728263	.718399	.723332	67,186,692	.00684	3 23 35.0	583.921	224.701	0.615	78,223	1 36 8
Earth.	⊕	1.016775	.983224	1.000000	92,885,000	.01677			365.256	1.000	66,582	59 8
Mars.	♂	1.665779	1.381602	1.523691	141,528,038	.09326	1 51 2.3	779.936	686.980	1.880	53,939	31 27
Jupiter.	♃	5.453663	4.951871	5.202798	483,261,892	.04825	1 18 41.4	398.884	4,332.585	11.862	29,204	4 59
Saturn.	♄	10.073278	9.004422	9.538852	886,014,410	.05605	2 29 39.2	378.092	10,759.220	29.458	21,561	2 1
Uranus.	♅	20.076300	18.288480	19.183380	1,781,847,251	.04636	0 46 20.9	369.656	30,686.821	84.018	15,202	42
Neptune.	♆	30.298160	29.774380	30.054370	2,791,600,157	.00899	1 46 58.7	367.489	60,126.720	164.622	12,139	22

NAME.	MEAN DIAMETER. REAL, IN MILES.	APPARENT, FROM ⊕.	ANGULAR DIAM. AT DISTANCE UNITY.	ROTATION, TIME OF SIDEREAL.	INCLINATION OF EQUATOR TO ORBIT.	MASS. ☉ = 1. DIVISORS.	⊕ = 1.	GRAVITY AT EQUATOR.	DENSITY, WATER = 1.	VOLUME, ⊕ = 1.	INTENSITY OF SOLAR LIGHT AND HEAT.
		″	Equatorial. ″	h. m. s.	° ′ ″			⊕ = 1.			⊕ = 1.
Mercury.	2,992	8′.7	6.68	?	?	5,000,000	.065	.46	6.85	.054	6.67
Venus.	7,660	38 .1	17.10	?	?	425,000	.785	.82	4.81	.851	1.91
Earth.	7,918		17.70	23 56 4.09	23 27 24	326,800	1.000	1.00	5.66	1.000	1.00
Mars.	4,211	17 .3	9.42	24 37 22.7	28 51	3,093,500	.124	.39	4.17	.239	.43
Jupiter.	85,700	40 .7	195.8	9 55 20	3 4	1,047.88	300.857	2.64	1.378	1,387.431	.037
Saturn.	70,000	17 .5	162.8	10 14	26 49	3,501.6	90.032	1.18	0.75	746.898	.011
Uranus.	32,000	3 .9	70.7	?	?	22,600	12.641	.90	1.28	72.359	.003
Neptune.	35,000	2 .8	77.0	?	?	19,380	16.761	.89	1.15	98.664	.001
Sun.	866,400	32′ 3″	32′	25 to 26 days		1	330.000	27.71	1.444	1,245.126	
Moon.	2,153	31′ 3″	4.81″	1 month		24,490,744	.0128	.15	3.57	.02012	

TABLE IV.—THE MINOR PLANETS.

NO.	NAME.	DISCOVERED.		ORBIT.			
		WHEN.	BY WHOM.	DIST.	ECCEN.	INCLIN.	PERIOD.
				⊕ = 1.		° ′	Years.
1	Ceres.	1801	Piazzi.	2.766	.080	10 36	4.60
2	Pallas.	1802	Olbers.	2.770	.240	34 42	4.61
3	Juno.	1804	Harding.	2.669	.256	13 3	4.36
4	Vesta.	1807	Olbers.	2.360	.090	7 8	3.63
5	Astræa.	1845	Hencke.	2.578	.190	5 19	4.14
6	Hebe.	1847	Hencke.	2.425	.201	14 46	3.78
7	Iris.	. .	Hind.	2.386	.231	5 27	3.69
8	Flora.	. .	Hind.	2.201	.157	5 53	3.27
9	Metis.	1848	Graham.	2.386	.123	5 36	3.69
10	Hygeia.	1849	DeGasparis.	3.149	.101	3 47	5.59
11	Parthenope.	1850	DeGasparis.	2.453	.099	4 36	3.84
12	Victoria.	. .	Hind.	2.333	.219	8 23	5.57
13	Egeria.	. .	DeGasparis.	2.576	.087	16 32	4.13
14	Irene.	1851	Hind.	2.590	.165	9 7	4.17
15	Eunomia.	. .	DeGasparis.	2.643	.188	11 44	4.30
16	Psyche.	1852	DeGasparis.	2.926	.136	3 4	5.01
17	Thetis.	. .	Luther.	2.474	.127	5 35	3.89
18	Melpomene.	. .	Hind.	2.296	.217	10 9	3.48
19	Fortuna.	. .	Hind.	2.441	.158	1 32	3.82
20	Massilia.	. .	DeGasparis.	2.409	.144	0 41	3.74
21	Lutetia.	. .	Goldschmidt.	2.435	.162	3 5	3.08
22	Calliope.	. .	Hind.	2.909	.104	13 44	4.96
23	Thalia.	. .	Hind.	2.625	.232	10 13	4.26
24	Themis.	1853	DeGasparis.	3.142	.117	0 48	5.57
25	Phocea.	. .	Chacornac.	2.402	.253	21 34	3.72
26	Proserpine.	. .	Luther.	2.656	.088	3 35	4.33
27	Euterpe.	. .	Hind.	2.347	.173	1 35	3.60
28	Bellona.	1854	Luther.	2.778	.150	9 21	4.63
29	Amphitrite.	. .	Marth.	2.555	.072	6 7	4.08
30	Urania.	. .	Hind.	2.364	.127	2 5	3.63
31	Euphrosyne.	. .	Ferguson.	3.156	.216	26 25	5.61
32	Pomona.	. .	Goldschmidt.	2.583	.082	5 29	4.16
33	Polyhymnia.	. .	Chacornac.	2.865	.338	1 56	4.85
34	Circe.	1855	Chacornac.	2.684	.110	5 26	4.40
35	Leucothea.	. .	Luther.	3.006	.214	8 10	5.22
36	Atalanta.	. .	Goldschmidt.	2.749	.298	18 42	4.56
37	Fides.	. .	Luther.	2.642	.175	3 7	4.30
38	Leda.	1856	Chacornac.	2.740	.156	0 58	4.54
39	Lætitia.	. .	Chacornac.	2.771	.111	10 21	4.61
40	Harmonia.	. .	Goldschmidt.	2.268	.046	4 15	3.42

NO.	NAME.	DISCOVERED.		ORBIT.			
		WHEN.	BY WHOM.	DIST.	ECCEN.	INCLIN.	PERIOD.
				⊕ = 1		° ′	Years.
41	Daphne.	. .	Goldschmidt.	2.768	.270	16 45	4.61
42	Isis.	. .	Pogson.	2.440	.226	8 35	3.81
43	Ariadne.	1857	Pogson.	2.204	.168	3 27	3.27
44	Nysa.	. .	Goldschmidt.	2.424	.149	3 41	3.77
45	Eugenia.	. .	Goldschmidt.	2.716	.082	6 34	4.48
46	Hestia.	. .	Pogson.	2.518	.162	2 17	4.00
47	Melete.	. .	Goldschmidt.	2.598	.237	8 1	4.19
48	Aglaia.	. .	Luther.	2.883	.128	5 0	4.90
49	Doris.	. .	Goldschmidt.	3.104	.076	6 29	5.47
50	Pales.	. .	Goldschmidt.	3.086	.238	3 8	5.42
51	Virginia.	. .	Ferguson.	2.649	.287	2 47	4.31
52	Nemausa.	1858	Laurent.	2.378	.063	10 14	3.67
53	Europa.	. .	Goldschmidt.	3.100	.005	7 24	5.46
54	Calypso.	. .	Luther.	2.610	.213	5 7	4.22
55	Alexandra.	. .	Goldschmidt.	2.708	.199	11 47	4.55
56	Pandora.	. .	Searle.	2.769	.139	7 20	4.61
57	Mnemosyne.	1859	Luther.	3.160	.107	15 4	5.62
58	Concordia.	1860	Luther.	2.698	.041	5 2	4.43
59	Danaë.	. .	Goldschmidt.	2.975	.163	18 17	5.13
60	Olympia.	. .	Chacornac.	2.715	.119	8 36	4.47
61	Erato.	. .	Forster.	3.130	.170	2 12	5.54
62	Echo.	. .	Ferguson.	2.394	.185	3 34	3.73
63	Ausonia.	1861	DeGasparis.	2.397	.127	5 45	3.70
64	Angelina.	. .	Tempel.	2.678	.125	1 19	4.39
65	Cybele.	. .	Tempel.	3.421	.120	3 28	6.66
66	Maia.	. .	Tuttle.	2.654	.154	3 4	4.32
67	Asia.	. .	Pogson.	2.421	.184	5 59	3.77
68	Hesperia.	. .	Schiaparelli.	2.995	.175	8 28	5.19
69	Leto.	. .	Luther.	2.775	.186	7 58	4.62
70	Panopea.	. .	Goldschmidt.	2.613	.183	11 39	4.22
71	Feronia.	. .	Peters.	2.266	.120	5 24	3.41
72	Niobe.	. .	Luther.	2.756	.174	23 19	4.57
73	Clytie.	1862	Tuttle.	2.665	.044	2 25	4.35
74	Galatea.	. .	Tempel.	2.778	.238	3 59	4.63
75	Eurydice.	. .	Peters.	2.670	.307	5 0	4.36
76	Freia.	. .	D'Arrest.	3.388	.188	2 2	6.24
77	Frigga.	. .	Peters.	2.672	.136	2 28	4.37
78	Diana.	1863	Luther.	2.623	.205	8 39	4.25
79	Eurynome.	. .	Watson.	2.443	.195	4 37	3.82
80	Sappho.	1864	Pogson.	2.296	.200	8 37	3.48
81	Terpsichore.	. .	Tempel.	2.856	.212	7 56	4.83
82	Alcmene.	. .	Luther.	2.760	.226	2 51	4.59
83	Beatrix.	1865	DeGasparis.	2.429	.084	5 2	3.79
84	Clio.	. .	Luther.	2.367	.238	9 22	3.64
85	Io.	. .	Peters.	2.659	.194	11 56	4.34
86	Semele.	1866	Tietjen.	3.091	.205	4 48	5.43
87	Sylvia.	. .	Pogson.	3.493	.083	10 51	6.53
88	Thisbe.	. .	Peters.	2.750	.167	5 9	4.56
89	Julia.	. .	Stephan.	2.534	.205	15 13	4.03
90	Antiope.	. .	Luther.	3.119	.173	2 16	5.51

NO.	NAME.	DISCOVERED.		ORBIT.			
		WHEN.	BY WHOM.	DIST.	ECCEN.	INCLIN.	PERIOD.
				⊕ = 1.		° ′	Years.
91	Ægina	. .	Stephan.	2.496	.066	2 10	3.94
92	Undina.	.	Peters.	3.192	.103	9 57	5.70
93	Minerva.	. .	Watson.	2.756	.140	8 37	4.58
94	Aurora.	. .	Watson.	3.160	.089	8 5	5.62
95	Arethusa.	1867	Luther.	3.069	.146	12 51	5.37
96	Ægle.	1868	Coggia.	3.054	.140	16 7	5.34
97	Clotho.	. .	Tempel.	2.669	.257	11 45	4.36
98	Ianthe.	. .	Peters.	2.684	.189	15 33	4.40
99	Dike.	. .	Borelli.	2.797	.238	13 9	4.68
100	Hecate.	. .	Watson.	2.993	.169	6 10	5.18
101	Helena.	. .	Watson.	2.573	.139	10 4	4.13
102	Miriam.	. .	Peters.	2.663	.254	5 6	4.35
103	Hera.	. .	Watson.	2.702	.081	5 22	4.44
104	Clymene.	. .	Watson.	3.180	.197	2 53	5.67
105	Artemis.	. .	Watson.	2.380	.176	21 39	3.67
106	Dione.	. .	Watson.	3.201	.195	4 42	5.73
107	Camilla.	.	Pogson.	3.560	.123	9 8	6.72
108	Hecuba.	1869	Luther.	3.193	.126	4 39	5.71
109	Felicitas.	. .	Peters.	2.695	.300	8 0	4.43
110	Lydia.	1870	Borelly.	2.733	.077	6 0	4.52
111	Ate.	. .	Peters.	2.592	.105	4 54	4.18
112	Iphigenia.	.	Peters.	2.433	.128	2 36	3.80
113	Amalthea.	1871	Luther.	2.376	.087	5 0	3.66
114	Cassandra.	. .	Peters.	2.676	.140	4 54	4.38
115	Thyra.	. .	Watson.	2.379	.194	11 36	3.69
116	Sirona.	. .	Peters.	2.767	.143	3 36	4.60
117	Lomia.	. .	Borelly.	2.991	.023	15 0	5.18
118	Peitho.	1872	Luther.	2.438	.161	7 48	3.81
119	Althea.	. .	Watson.	2.580	.083	5 48	4.15
120	Lachesis.	. .	Borelly.	3.121	.047	7 0	5.52
121	Hermione.	. .	Watson.	3.459	.125	7 36	6.43
122	Gerda.	. .	Peters.	3.215	.040	1 36	5.76
123	Brunhilda.	. .	Peters.	2.695	.122	6 24	4.42
124	Alceste.	. .	Peters.	2.630	.077	2 54	4.26
125	Liberatrix.	. .	Prosp'r Henry.	2.744	.077	4 36	4.54
126	Velleda.	. .	Paul Henry.	2.440	.107	2 54	3.81
127	Johanna.	. .	Prosp'r Henry.	2.756	.067	8 18	4.58
128	Nemesis.	. .	Watson.	2.751	.128	6 18	4.56
129	Antigone.	1873	Peters.	2.876	.208	12 12	4.88
130	Electra.	. .	Peters.	3.123	.208	22 54	5.52
131	Vala.	. .	Peters.	2.420	.081	4 36	3.77
132	Æthra.	. .	Watson.	2.600	.383	24 54	4.10
133	Cyrene.	. .	Watson.	3.058	.140	7 12	5.35
134	Sophrosyne.	. .	Luther.	2.563	.118	11 36	4.10
135	Hertha.	1874	Peters.	2.428	.205	2 18	3.78
136	Austria.	. .	Palisa.	2.286	.084	9 36	3.46
137	Melibœa.	. .	Palisa.	3.126	.208	13 24	5.53
138	Tolosa.	. .	Perrotin.	2.449	.162	3 12	3.83
139	Juewa.	. .	Watson.	2.779	.177	11 0	4.63
140	Siwa.	. .	Palisa.	2.731	.217	3 12	4.51

And about 100 others.

TABLE V.—ELEMENTS OF THE SATELLITES.

NO.	NAME.	MEAN DISTANCES.		SIDEREAL PERIOD.		DIAM.
		Pl. = 1.	Miles.	d. h. m.	d.	Miles.
	Mars.					
1	Phobos.	1.39	5,820	7 39	0.32	10?
2	Deimos.	3.48	14,600	1 6 18	1.26	30?
	Jupiter.					
1	Io.	6.05	259,000	1 18 28	1.77	2500
2	Europa.	9.62	412,000	3 13 14	3.55	2200
3	Ganymede.	15.35	658,000	7 3 43	7.15	3700
4	Callisto.	26.99	1,156,000	16 16 32	16.69	3200
	Saturn.					
1	Mimas.	3.36	115,000	22 37	0.94	1000
2	Enceladus.	4.31	150,000	1 8 53	1.37	?
3	Tethys.	5.34	185,000	1 21 18	1.88	500
4	Dione.	6.84	238,000	2 17 41	2.73	500
5	Rhea.	9.55	332,000	4 12 25	4.51	1200
6	Titan.	22.15	770,000	15 22 41	15.94	3200
7	Hyperion.	26.80	988,000	21 7 7	21.29	?
8	Japetus.	64.36	2,254,000	79 7 53	79.33	1800
	Uranus.	Motion	Retrograde.			
1	Ariel.	7.44	119,000	2 12 28	2.52	?
2	Umbriel.	10.37	166,000	4 3 27	4.14	?
3	Titania.	17.01	272,000	8 16 55	8.71	?
4	Oberon.	22.75	364,000	13 11 6	13.46	?
	Neptune.	Motion	Retrograde.			
1	Satellite.	12.00	210,000	5 21 8	5.87	?

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NOTE.—*Figures refer to pages.*

an. 20.

Horizon at Midnight, Dec. 21; at 10 P. M., Jan. 20; at 8 P. M., Feb. 19.

Horizon at Midnight, March 21; at 10 P. M., April 20; at 8 P. M., May 21.

Horizon at Midnight, Dec. 21; at 10 P. M., Jan. 20; at 8 P. M., Feb. 19.

Horizon at Midnight, June 21; at 10 P. M., July 22; at 8 P. M., Aug. 23.

PLATE VI.—Horizon at Midnight, Sept. 23; at 10 P. M., Oct. 23; at 8 P. M., Nov. 22.

PLATE VII.—Horizon at Midnight, Nov. 22; at 10 P. M., Dec. 21; at 8 P. M., Jan. 20.

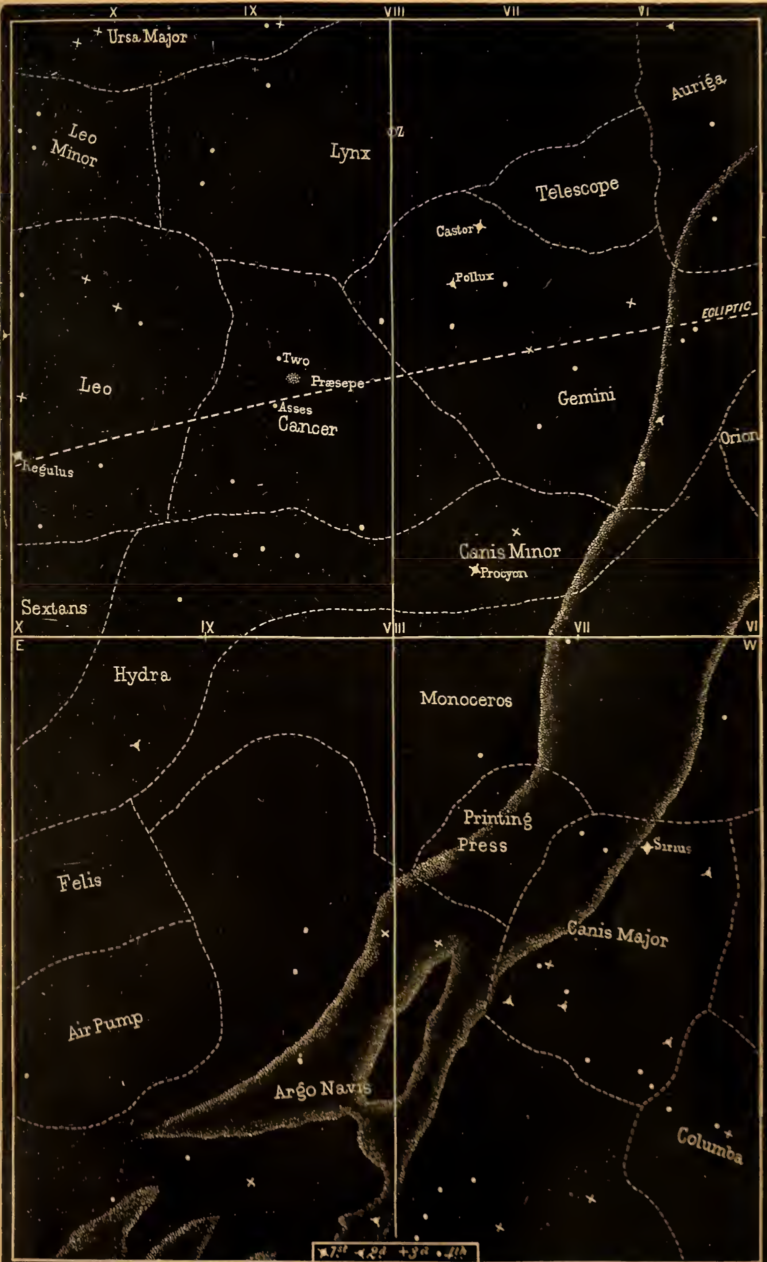

PLATE VIII.—Horizon at Midnight, Jan. 20; at 10 P. M., Feb. 19; at 8 P. M., March 21.

PLATE IX.—Horizon at Midnight, March 21; at 10 P. M., April 20; at 8 P. M., May 21.

PLATE X.—Horizon at Midnight, May 21; at 10 P. M., June 21; at 8 P. M., July 22.

PLATE XI.—Horizon at Midnight, July 22; at 10 P. M., Aug. 23; at 8 P. M., Sept. 23.

PLATE XII.—Horizon at Midnight, Sept. 23; at 10 P. M., Oct. 23; at 8 P. M., Nov. 22.